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Platform Service Supply Chain Network Equilibrium Model with Data Empowerment

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Abstract: With the rapid development of information and communication technology, data empowerment has become an important way for platform service supply chain (PSSC) members to obtain a competitive advantage. Based on the three-level PSSC network structure composed of service providers, platform operators, and demand markets, this paper assumes that platform operators empower service providers to improve service quality, and PSSC members invest in data security risk control. Then, using variational inequality and equilibrium theory, a supply chain network equilibrium model considering data empowerment is constructed, and the equilibrium conditions of the whole network are obtained. Based on numerical examples, this paper analyzes the impact of the sensitivity of the demand market to service quality, the relative importance of service providers' service quality improvement level, the data empowerment cost of PSSC members, and the data security risk control investment of PSSC members on the equilibrium state of the supply chain network. The results show the following: because the service quality is produced by the cooperation between service providers and platform operators, platform operators may have free-riding behavior and are only willing to invest a fixed data empowerment cost to ensure the essential service quality; data security risk control investment is an important factor affecting service sales; and when supply chain network members reduce data security risk control investment, consumers' willingness to pay for services will be reduced, resulting in a decline in the overall profit of the supply chain network.

Keywords: platform service supply chain; data empowerment; network equilibrium; variational inequality

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1. Introduction

Driven by information and communication technology (ICT) such as the Internet and mobile Internet, the service platform has developed rapidly as a new business model, and PSSC has attracted extensive attention all over the world [1,2]. In the three-level PSSC composed of service providers, platform operators, and demand markets, some platform operators take the service platform as the carrier to obtain or improve the overall capacity of the supply chain through the application of data and digital technology [3,4]. This behavior is called data empowerment and is believed to help supply chain member enterprises win an edge in the increasingly fierce market competition [5]. To this end, many powerful platform operators have been empowering service providers with data to continuously strengthen their value creation capabilities and the synergy advantages of the overall supply chain. For example, based on the in-depth mining of driving data, Didi Travel builds a personalized recommendation system, through digital technologies such as big data and cloud computing, from the lowest travel cost, the highest driver efficiency, and the best transportation system to help the drivers in the platform maximize the accurate matching of users [6,7].

However, data empowerment is not always beneficial [8]. On the one hand, with the upgrading of consumption and the progress of technology, demand for high-quality services has become increasingly prominent. Platform operators pay more and more attention to improving the overall service quality of the supply chain through data empowerment [9]. For example, MeiTuan Taxi, an online car-hailing platform, uses background data and digital technology to improve the timeliness and accuracy of travel and the communication quality of the platform itself [10]. On the other hand, regarding data empowerment, the high-frequency use of data and digital technology intensifies the possibility of PSSC encountering data security risks [11]. In 2016, the American enterprise Uber suffered a data leak, which leaked the privacy information of tens of millions of users and drivers and caused significant direct economic losses to Uber [12]. In addition, the service platform has typical bilateral market characteristics, and there are significant network externalities between users, which leads to the spontaneous aggregation of bilateral users to the service platform [13]. Therefore, in reality, the PSSC is usually a complex network with multiple levels, including the service provider, platform operator, and demand market. Nash non-cooperative competition is conducted among members at the same level, and cooperation and transactions are conducted among members at different levels [14]. In the context of data empowerment, it is of great practical significance to study the interactive impact of service quality improvement and data security risk avoidance on decision makers in the PSSC network.

In terms of theoretical research, on the one hand, scholars affirmed the role of data empowerment in obtaining or improving the overall capacity of the supply chain through case studies and confirmed that data empowerment can promote the value co-creation of the PSSC based on empirical analysis [15,16]. These studies have laid a theoretical foundation for the construction of the model in this paper. In addition, service quality is an inevitable hot topic in PSSC [17]. However, scholars' research on service quality is based chiefly on a single supply chain, and there is less research on service quality in the supply chain network. Therefore, this paper focuses on the micro perspective of improving service quality capability and considers the decision-making interaction behavior of PSSC network members in this process. On the other hand, risk management is an important issue that cannot be ignored in PSSC [18]. Presently, scholars' research on risk management in PSSC mainly focuses on supply risk, procurement risk, and decision-makers' risk attitude [19,20]. Although some scholars have begun to study the network security risk, few scholars specifically focus on the data security risk [21]. Therefore, under the background of data enabling the behavior of the service platform, it is urgent to conduct unique research on data security risk management of the PSSC.

Based on the above problems, we build a three-level PSSC network structure composed of service providers, platform operators, and demand markets. We study the network equilibrium of the PSSC considering service quality improvement and data security risk control investment under data empowerment, and we explore its influence on the decision-making behavior of network members and the interaction between superiors and subordinates. We establish an equilibrium model of the overall network through variational inequality, and the equilibrium state of the whole network is obtained.

This paper makes contributions in the following three aspects. Firstly, we build a PSSC network equilibrium model of service quality improvement and data security risk control investment under data empowerment and analyze the interest relationship between upstream and downstream decision makers. Secondly, we discuss the impact of consumers' perception of service quality, the relative importance of service providers' service quality improvement level, data empowerment cost, and data security risk control investment on the profits of PSSC network members and the equilibrium state of the whole network. Finally, we find that because the service quality is produced by the cooperation between service providers and platform operators, platform operators may have free-riding behavior and are only willing to invest a fixed data empowerment cost to ensure the basic service quality. Data security risk control investment is an important factor affecting service sales. When supply chain network members reduce data security risk control investment, consumers' willingness to pay for services will be reduced, resulting in a decline in the overall profit of the supply chain network.

The remainder of this paper is organized as follows. In Section 2, we review the relevant literature. The symbols and assumptions of the model are described in Section 3. In Section 4, we use variational inequality to derive the equilibrium conditions of service providers and platform operators. Finally, we obtain the network equilibrium conditions of the whole PSSC. In Section 5, a numerical example is given to verify the model's effectiveness and analyze the influence of relevant factors on the equilibrium results. In Section 6, we have a series of discussions on the calculation results and put forward some opinions on management and economics. Section 7 summarizes this study, puts forward specific suggestions for different subjects, and describes the shortcomings of this study and the future research direction.

2. Literature Review

This work is closely related to the platform service supply chain, data empowerment, and supply chain network equilibrium.

2.1. Platform Service Supply Chain

With the growing importance of the service industry, scholars have begun to pay attention to research on the service supply chain [22,23]. Initially, scholars believed that the service supply chain was only a supplement to the manufacturing supply chain [24]. With the deepening of research, scholars gradually realized that service has the characteristics of intangibility and perishability, and they began to distinguish the service supply chain from the manufacturing supply chain [25]. At present, the widely accepted structure of the service supply chain is as follows: service provider–service integrator–customer [26]. The emergence of a service platform has overturned the traditional supply chain business model. Lin et al. [27] defined the service supply chain using the platform's strategy as the PSSC. At present, scholars' research on PSSC mainly focuses on service quality management [17,28,29], competition and cooperation strategy [30,31], coordination mechanism design [19,32], and risk management [18,20]. With the rapid development of digital technology, data has become an important resource for supply chain members to obtain competitive advantage [33]. Liu et al. [34] studied the sales mode selection of the platform under the influence of data-driven marketing. They pointed out that when the efficiency of data-driven marketing is higher, the platform is more willing to adopt the resale mode. Cenamor et al. [35] believed that with the help of data and digital technology, the service platform could provide more advanced services and improve the service quality of the supply chain. Massimino et al. [11] pointed out that compared with the benefits of using data on the platform, the research on data security risks has been ignored.

From the above research on PSSC, we can find that scholars have realized that the application of data and digital technology can improve service quality and lead to data security risks. However, few studies consider these two aspects simultaneously and study the decision-making behavior and profit distribution strategy of PSSC members from a micro perspective through quantitative analysis.

2.2. Data Empowerment

The term "empowerment" comes from the research on empowerment in the field of organizational behavior, emphasizing the process of improving subordinates' "effort performance" expectations or self-efficacy [36]. Leong et al. [37] pointed out three key dimensions of empowerment: structural empowerment, psychological empowerment, and resource empowerment. Zhang et al. [16], however, believed that structural and psychological empowerment did not reflect the connotation of empowerment. In contrast, resource empowerment made up for the deficiency of structural and psychological empowerment. Data empowerment has increasingly become the core of resource empowerment in the

Internet era. From the perspective of capability, data empowerment is divided into three dimensions: intelligence capability, connectivity capability, and analysis capability [38]. Among them, intelligence capability is the ability to perceive and capture information through hardware facilities under the condition of a low degree of manual participation, connection capability is the ability to connect with various intelligent products through communication technology, and analysis capability is the ability to mine customer needs through logical processing and scene simulation of a large number of customer behavior data. Sun et al. [15] introduced data empowerment into the WEEE collection business ecosystem. They proposed that the online platform can further expand the application field of data empowerment by empowering suppliers, customers, and other participants through structure, psychology, and resources. Zaki et al. [39] believe that the "enabling role" of a digital platform comes from its network hub position and cutting-edge information technology. The resulting resource integration and data-processing ability can significantly enable the innovation of platform participants' business models and technical products. Participants on the platform realized a higher frequency of transaction interaction and faster innovation interaction through digital tools. Kache and Seuring [40] explored the opportunities and challenges that big data analysis brings to enterprises and supply chains through empirical analysis. Núñez-Merino et al. [41] analyzed and evaluated the relationship between information and digital technology and lean supply chain management through a systematic literature review method. However, most of the above studies are based on empirical analysis or case analysis to qualitatively study the relationship between data empowerment, platform enterprises, and the supply chain. Few studies quantitatively study the relationship between data empowerment and supply chain members' decision making by constructing mathematical models.

Xiao et al. [5] opine that data empowerment of an e-commerce platform can help retailers induce demand by constructing the supply chain game model between the e-commerce platform and multiple retailers. Their paper analyzes the conditions for retailers to accept the data empowerment of the platform and discusses the optimal decision for the data empowerment level of the platform. Liu et al. [8] used evolutionary game theory to analyze the impact of agency fee, enabling cost, and service price elasticity coefficient on the cooperation state between logistics platform and logistics service provider. The results show that the platform should charge a reasonable agency fee in order to achieve ecological cooperation. Both of them use quantitative research methods to bring data empowerment into the supply chain research. However, their research is based on the supply chain of an e-commerce platform and takes tangible products as the research object. Our research is based on a PSSC and takes intangible service as the research object. Moreover, their supply chain is a single chain structure, and we realize that the PSSC is a complex network in reality. Therefore, we extend the supply chain structure to the supply chain network.

2.3. Supply Chain Network Equilibrium

The supply chain network is a complex dynamic system. Non-cooperative competition among similar members in the network forms a Nash equilibrium state. Based on ensuring the interests of all members, exploring the equilibrium conditions of the supply chain network and realizing the equilibrium conditions of maximizing the overall interests of the system is one of the crucial topics for academic and industrial circles. Nagurney et al. [42] combined variational inequality with equilibrium theory for the first time to build a supply chain network equilibrium model, which can not only solve the equilibrium problem between decision makers of a two-level supply chain but also determine the decision-making behavior of decision makers at all levels when the whole supply chain reaches equilibrium, which provides a new research method and research perspective for the research of supply chain network equilibrium. Because the equilibrium model can sufficiently express the complex interactive relationship between members in the system, it is widely used in many fields. In terms of research breadth, domestic and foreign scholars have used variational inequality to build a supply chain equilibrium network model involving automobile, finance, tourism, and other industries to solve the equilibrium problem of industry development [43–46]. In terms of research depth, follow-up scholars have expanded from different angles such as closed-loop, multi-cycle, dual-channel, and uncertain demand to make the research closer to the actual situation of the market [13,14,47–50]. With the rise of the service economy, research on the network equilibrium of the service supply chain has also received extensive attention. Nagurney et al. [51] first established a static network equilibrium model of a service supply chain to study the influence of price and quality competition on supply chain network members. Then, Nagurney and Wolf [52] studied the dynamic equilibrium of a supply chain network, looking at differences in service and quality by using Cournot–Nash–Bertrand theory. On this basis, Nagurney et al. [53] established static and dynamic equilibrium models of service supply chain networks to study the impact of quality and price competition on the equilibrium state of the network. Peng et al. [54] discussed the influence of product and service capability constraints and the change of product service integration rate on the network equilibrium state.

At present, scholars have done a lot of research on service quality under service supply chain network equilibrium. Still, few works of literature consider the improvement of service quality and the investment in data security risk control under the background of data empowerment.

3. Problem Statement and Formulation

3.1. Problem Description

The PSSC network constructed in this paper is a three-layer network structure composed of service providers, platform operators, and demand markets. The first tier consists of m service providers, who are responsible for the actual provision of services. For example, in the online car-hailing PSSC, online car-hailing drivers are responsible for providing real travel services. The second tier is composed of n platform operators, who sell the services of service providers through websites, mobile terminal apps, and other forms. For example, platform operators such as Didi Travel and Caocao Travel match the supply and demand of travel services through the service platform and charge a certain proportion of commission. The third tier consists of o demand markets. Consumers in the demand market can choose services from different service providers from different platform operators. The specific network structure is shown in Figure 1, in which each node represents a participant in the network, and each link between nodes represents an economic transaction activity.

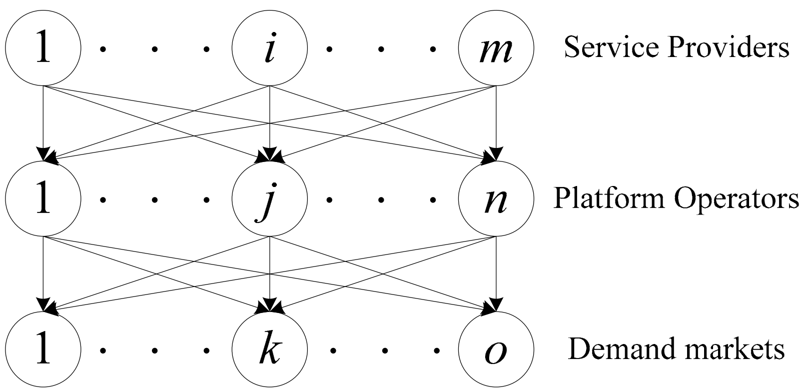


Figure 1. Platform service supply chain network structure.

In the whole process of service transaction, to win a competitive advantage, platform operators choose to empower service providers through data and digital technology to improve the service quality of service providers, such as communication quality, travel route optimization, and so on. At the same time, platform operators will continue to improve their service quality, such as platform construction quality, error handling, supervision of travel process, and so on. The synergistic improvement of the service quality of the two parties has brought an excellent consumption experience to consumers in the demand market, which has increased market activity. However, as data has been widely used, the number of members exposed to data has risen sharply, and insufficient attention has been paid to data security, which makes the supply chain more likely to encounter data security risks, data leakage, and other problems that occur frequently. Disclosing consumers' private information also causes direct economic losses to supply chain enterprises. Service providers and platform operators need to jointly invest funds for data security risk control to reduce the probability of risk occurrence.

Nash equilibrium, also known as non-cooperative game equilibrium, is widely used in supply chain management. When all stakeholders make the best decision together and have no motivation to change their decision-making behavior, the supply chain reaches Nash equilibrium. For complex PSSC networks with a service provider layer, platform operator layer, and demand market layer, under ideal conditions, in each layer, all competing members form Nash equilibrium in the process of production and transaction, which can be called supply chain network equilibrium. In this context, the finite-dimensional variational inequality method can be used to obtain the optimal conditions of stakeholders in economic equilibrium.

Definition 1. *Referring to the research of Nagurney et al.* [21,51,52], *the finite-dimensional variational inequality problem, V (F, κ), determines where* $X^{*}\in\kappa$, *where X is a vector in* R^N *and F(X) is a continuous function, so that F(X):* $X\in\kappa\subset R^N$, *and*

$$\langle F(X^*), X - X^* \rangle \geq 0, \forall X \in \kappa \tag{1}$$

where R^N represents the N-dimensional Euclidean space, κ is a given closed convex set, and $\langle .,. \rangle$ is the inner product of R^N. Thus, the optimal solution to equilibrium is denoted by *.

3.2. Notations Description

In order to facilitate the construction of the model and analysis of problems, the relevant notations are shown in Table 1.

Table 1. Notation description.

Notations	Descriptions
$i \in \{1,2,\ldots,m\}$	Set of service providers, with m service providers in total.
$j \in \{1,2,\ldots,n\}$	Set of platform operators, with n platform operators in total.
$k \in \{1,2,\ldots,o\}$	Set of demand markets, with o demand markets in total.
Q_{ijk}	The non-negative service volume from i to k via j.
S_i	Number of services produced by service provider i.
x_i	Data empowerment improves the service quality of service provider i.
y_j	Data empowerment improves the service quality of platform operator j.
α	Influence coefficient of data empowerment on service provider i's service quality improvement cost.
β	Influence coefficient of data empowerment on platform operator j's service quality improvement cost.
w_i	Data security risk level of service provider i.
φ_i	Influence coefficient of data security risk level of service provider i.
δ_j	Influence coefficient of data security risk level of platform operator j.
r_j	Data security risk level of platform operator j.
$\overline{w_i}$	Average data security risk level of service providers.
$\overline{r_j}$	Average data security risk level of platform operators.
ℓ	Percentage of commission charged by platform operators to service providers.
P_i	Probability of data security risk for service provider i.
P_j	Probability of data security risk of platform operator j.

Table 1. *Cont.*

Notations	Descriptions
D_i	Loss of data security risk borne by service provider *i*.
D_j	Loss of data security risk borne by platform operator *j*.
$\overline{\mu}\left(w_i, r_j\right)$	Data security risk level of the whole platform service supply chain network.
$q_{ij}\left(x_i, y_j\right)$	The service quality perceived by the demand market.
$\rho_{ijk}\left(Q_{ijk}, q_{ij}\left(x_i, y_j\right), \overline{\mu}\left(w_i, r_j\right)\right)$	The demand price at *k* associated with service *i* transported via *j*.
$f_i\left(Q_{ijk}\right)$	The total production cost of service provider *i*.
$c_{ijk}\left(Q_{ijk}\right)$	The total transportation cost associated with service *i* transported via *j*.
$h_i(x_i)$	Service quality improvement cost of service provider *i* under data empowerment.
$v_i(w_i)$	Data security risk control investment cost of service provider *i*.
$\eta_j\left(y_j\right)$	Service quality improvement cost of platform operator *j* under data empowerment.
$I_j\left(r_j\right)$	Data security risk control investment cost of platform operator *j*.

3.3. Model Assumptions

(1) In the network structure of the PSSC, service providers, platform operators, and demand market nodes are rational decision makers, respectively pursuing their own profit or utility maximization. The supply chain network reaches an equilibrium state through Nash non-cooperative competition of members at the same level and cooperation and interaction among members at the different levels [43,44].

(2) The relevant cost functions of service providers and platform operators are continuously differentiable convex functions [45,46].

(3) The transaction cost of the service in the transmission process shall be borne by the platform operators [52].

(4) Service quality is jointly determined by the service quality improvement level of data empowerment on service providers and platform operators. It is affected by the sensitivity coefficient of service quality and the importance of the service quality improvement level. Referring to Roels et al. [55], Cobb Douglas's cooperative production function is adopted, which is specifically expressed as follows:

$$q_{ij}\left(x_i, y_j\right) = \lambda x_i^{\theta} y_j^{1-\theta} \tag{2}$$

where, $0 < \theta < 1$, represents the importance of service provider data empowerment to improve service quality behavior and service quality output, that is, the dependence of service quality output on service providers. The larger the θ, the stronger the dependence of service quality production on service provider data enabling investment, and the more important the service provider is. Expected output meets $q_{ij}(x_i, 0) = q_{ij}\left(0, y_j\right) = 0$, and $\lim\limits_{x_i \to \infty} \frac{\partial\left(x_i, y_j\right)}{\partial x_i} = \lim\limits_{y_j \to \infty} \frac{\partial\left(x_i, y_j\right)}{\partial y_j} = \infty$. The former means that if one party does not make data enabling input to improve service quality, there will be no service quality output. The latter means that if one party's data empowerment investment is substantial, the other party will benefit greatly from the cooperation with little effort.

(5) The data security risk level of the PSSC network is expressed by the weighted average of the average data security risk level faced by service providers and platform operators, as shown below:

$$\overline{\mu} = \frac{\overline{w_i} + \overline{r_j}}{2} \tag{3}$$

where $\overline{w_i} = \frac{1}{m} \sum\limits_{i=1}^{m} w_i$, $\overline{r_j} = \frac{1}{n} \sum\limits_{j=1}^{n} r_j$.

4. Model Building

4.1. Behavior of the Service Providers and Their Equilibrium Conditions

The service provider i's decision involves service volume, its own service quality level improved by data empowerment, and its own data security risk level. In addition, m service providers take their own profit maximization as the decision-making goal, and the profit maximization function is

$$MaxU_i = \sum_{j=1}^{n}\sum_{k=1}^{o}\rho_{ijk}\left(Q_{ijk}, q_{ij}\left(x_i, y_j^*\right), \overline{\mu}\left(w_i, r_j^*\right)\right)Q_{ijk} - f_i\left(Q_{ijk}\right) - \ell\sum_{j=1}^{n}\sum_{k=1}^{o}\rho_{ijk}\left(Q_{ijk}, q_{ij}\left(x_i, y_j^*\right), \overline{\mu}\left(w_i, r_j^*\right)\right)Q_{ijk} - h_i(x_i) - v_i(w_i) - w_i \times \overline{\mu}\left(w_i, r_j^*\right) \times D_i \tag{4}$$

so that

$$s_i = \sum_{j=1}^{n}\sum_{k=1}^{o} Q_{ijk} \tag{5}$$

$$Q_{ijk} \geq 0, \forall j, k \tag{6}$$

$$x_i \geq 0 \tag{7}$$

$$0 < w_i \leq 1 \tag{8}$$

where the first item of Equation (4) is the income obtained by service provider i from selling its services to consumers in o demand markets through n platform operators. The second item is the production cost of services, which is related to service volume. The third item is the agent sales fee paid to the platform operator. The fourth item is the cost of service quality improvement under data empowerment, which is related to the influence the coefficient of service quality improvement cost and the level of service quality improvement of service providers by data empowerment. The fifth item is the input cost of data security risk control, which is related to the influence coefficient of data security risk level and the data security risk level of the service provider, specifically expressed as $v_i(w_i) = \varphi_i\left(\frac{1}{\sqrt{w_i}} - 1\right)$, where $v_i(0) = \infty$, which indicates that when the data security risk is 0, the input cost is infinite; and $v_i(1) = 0$, which indicates that when the data security risk is 1, the input cost is 0. The last item is the economic loss cost of encountering a data security risk. The probability of encountering a risk is related to its data security risk level and the data security risk level of the whole supply chain network, expressed as $P_i = w_i \times \overline{\mu}\left(w_i, r_j\right)$. Constraint (5) indicates that the number of services produced by each service provider is equal to the sum of the number of services sold to all demand markets through all platform operators. Constraint (6) guarantees that the services volumes are non-negative. Constraint (7) represents the non-negative constraint of the service quality improvement level of the service provider. Constraint (8) represents the value range of the data security risk level of the service provider, where $w_i = 0$ represents that the service provider i is in a state of complete data security, and $w_i = 1$ represents that the service provider i is in a state of complete data security risk. Referring to the research of Nagurney et al. [21], we believe that complete data security does not exist in reality, and service providers need to invest a certain cost to maintain a certain level of data security.

Theorem 1. *Variational inequality formulations of service provider: Assuming that the cost function of each service provider is a continuously differentiable convex function, according to formula (1), the optimal condition of all service providers can be equivalent to the following variational inequality, that is, to determine* $\left(Q_{ijk}^*, x_i^*, w_i^*\right) \in \kappa^1$, *one must satisfy the following:*

$$\begin{aligned}
&\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o}\left[\frac{\partial f_i\left(Q_{ijk}^*\right)}{\partial Q_{ijk}} + (\ell-1)\rho_{ijk}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right) - \sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial\rho_{ihl}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)}{\partial Q_{ijk}}Q_{ihl}^*\right] \times \left(Q_{ijk} - Q_{ijk}^*\right)\\
&+\sum_{i=1}^{m}\left[\frac{\partial h_i\left(x_i^*\right)}{\partial x_i} - \sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial\rho_{ihl}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)}{\partial x_i}Q_{ihl}^*\right] \times \left(x_i - x_i^*\right)\\
&+\sum_{i=1}^{m}\left[\frac{\partial v_i\left(w_i^*\right)}{\partial w_i} + \left(\overline{\mu}\left(w_i^*, r_j^*\right) + \frac{w_i^*}{2m}\right)D_i - \sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial\rho_{ihl}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)}{\partial w_i}Q_{ihl}^*\right] \times \left(w_i - w_i^*\right) \geq 0
\end{aligned} \tag{9}$$

Proof. Referring to Nagurney et al. [21,51,52], if the service provider i cannot improve its profit by changing its own decision variables, the service provider will be in the optimal equilibrium state. According to Definition 1, there is a transformation relationship between the variational inequality method and the optimization problem, that is,

$$\begin{aligned}&-\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o}\frac{\partial U_i\left(Q_{ijk}^*,x_i^*,w_i^*\right)}{\partial Q_{ijk}}\times\left(Q_{ijk}-Q_{ijk}^*\right)\\&-\sum_{i=1}^{m}\frac{\partial U_i\left(Q_{ijk}^*,x_i^*,w_i^*\right)}{\partial x_i}\times\left(x_i-x_i^*\right)\\&-\sum_{i=1}^{m}\frac{\partial U_i\left(Q_{ijk}^*,x_i^*,w_i^*\right)}{\partial w_i}\times\left(w_i-w_i^*\right)\geq 0\end{aligned} \tag{10}$$

In order to obtain (9) from (10), we note that

$$-\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o}\frac{\partial U_i\left(Q_{ijk}^*,x_i^*,w_i^*\right)}{\partial Q_{ijk}}=\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o}\left[\frac{\partial f_i\left(Q_{ijk}^*\right)}{\partial Q_{ijk}}+(\ell-1)\rho_{ijk}\left(Q_{ijk}^*,q_{ij}\left(x_i^*,y_j^*\right),\overline{\mu}\left(w_i^*,r_j^*\right)\right)-\sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial\rho_{ihl}\left(Q_{ijk}^*,q_{ij}\left(x_i^*,y_j^*\right),\overline{\mu}\left(w_i^*,r_j^*\right)\right)}{\partial Q_{ijk}}Q_{ihl}^*\right] \tag{11}$$

$$-\sum_{i=1}^{m}\frac{\partial U_i\left(Q_{ijk}^*,x_i^*,w_i^*\right)}{\partial x_i}=\sum_{i=1}^{m}\left[\frac{\partial h_i\left(x_i^*\right)}{\partial x_i}-\sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial\rho_{ihl}\left(Q_{ijk}^*,q_{ij}\left(x_i^*,y_j^*\right),\overline{\mu}\left(w_i^*,r_j^*\right)\right)}{\partial x_i}Q_{ihl}^*\right] \tag{12}$$

$$-\sum_{i=1}^{m}\frac{\partial U_i\left(Q_{ijk}^*,x_i^*,w_i^*\right)}{\partial w_i}=\sum_{i=1}^{m}\left[\frac{\partial v_i\left(w_i^*\right)}{\partial w_i}+\left(\overline{\mu}\left(w_i^*,r_j^*\right)+\frac{w_i^*}{2m}\right)D_i-\sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial\rho_{ihl}\left(Q_{ijk}^*,q_{ij}\left(x_i^*,y_j^*\right),\overline{\mu}\left(w_i^*,r_j^*\right)\right)}{\partial w_i}Q_{ihl}^*\right] \tag{13}$$

The variational inequality (9) is obtained by substituting Equations (11)–(13) into inequality (10). □

4.2. Behavior of the Platform Operators and Their Equilibrium Conditions

The platform operator j's decision involves its own service quality level, which is improved by data empowerment, and its own data security risk level. In addition, n platform operators take their own profit maximization as the decision-making goal, and the profit maximization function is as follows:

$$MaxU_j=\sum_{i=1}^{m}\sum_{k=1}^{o}\ell\rho_{ijk}\left(Q_{ijk}^*,q_{ij}\left(x_i^*,y_j\right),\overline{\mu}\left(w_i^*,r_j\right)\right)-\sum_{i=1}^{m}\sum_{k=1}^{o}c_{ijk}\left(Q_{ijk}^*\right)-\eta_j\left(y_j\right)-I_j\left(r_j\right)-r_j\times\overline{\mu}\left(w_i^*,r_j\right)\times D_j \tag{14}$$

so that

$$y_j\geq 0 \tag{15}$$

$$0<r_j\leq 1 \tag{16}$$

The first item of Equation (14) is the commission charged by the platform operator to the service provider. The second is the transaction cost of services, such as the information cost and communication cost generated in the transaction process, which is related to the number of services. The third item is the cost of service quality improvement under data empowerment, which is associated with the influence coefficient of the service quality improvement cost and the level of service quality improvement of platform operators by data empowerment. The fourth item is the input cost of data security risk control, which is related to the influence coefficient of the data security risk level and the data security risk level of platform operators. The last item is the economic loss cost borne by the platform operator when encountering the data security risk. The probability of encountering the risk is related to the data security risk level and the data security risk level of the whole supply chain network, which is expressed as $P_j=r_j\times\overline{\mu}\left(w_i,r_j\right)$. Constraint (15) represents the non-negative constraint of the service quality improvement level of the platform operator. Constraint (16) represents the value range of the data security risk level of the platform operator. In addition, $r_j=0$ represents that the platform operator j is in a state of complete data security, and $r_j=1$ represents that the platform operator j is in a state of complete data security risk. Referring to the research of Nagurney et al. [21], we believe that complete data security does not exist in reality, and platform operators need to invest a certain cost to maintain a certain level of data security.

Theorem 2. *Variational inequality formulations of platform operator: Nash equilibrium game of non-cooperative competition among platform operators. The relevant cost function of each platform operator is a continuously differentiable convex function, so the optimization function of each platform operator can be transformed into the following form according to Definition 1. That is, to determine* $\left(Q_{ijk}^*, y_j^*, r_j^*\right) \in \kappa^2$, *one must satisfy the following:*

$$\begin{aligned}&\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{o}\left[\frac{\partial c_{ijk}\left(Q_{ijk}^*\right)}{\partial Q_{ijk}} - \ell\rho_{ijk}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)\right] \times \left(Q_{ijk} - Q_{ijk}^*\right)\\ &+\sum_{j=1}^{n}\left[\frac{\partial \eta_j\left(y_j^*\right)}{\partial y_j}\right] \times \left(y_j - y_j^*\right)\\ &+\sum_{j=1}^{n}\left[\frac{\partial I_j\left(r_j^*\right)}{\partial r_j} + \left(\overline{\mu}\left(w_i^*, r_j^*\right) + \frac{r_j^*}{2n}\right) \times D_j\right] \times \left(r_j - r_j^*\right) \geq 0\end{aligned} \tag{17}$$

Proof. Similar to the proof of Theorem 1. □

4.3. The Entire Platform Service Supply Chain Network Equilibrium Conditions

Supply chain network equilibrium means that the decision-making behavior of any node in the network reaches the equilibrium state, and the equilibrium flow and equilibrium price meet the sum of the above variational inequalities. That is, the optimal decision is made when the decisions of other nodes are optimal. When the number and price of services among the node members meet the sum of variational inequalities from service providers to platform operators and then to the demand market, the network is in equilibrium.

Theorem 3. *Variational inequality formulations of the entire PSSC network: The optimal equilibrium condition of the interests of all decision makers in the PSSC network can be transformed into the following variational inequality form. That is, to determine* $\left(Q_{ijk}^*, x_i^*, w_i^*, y_j^*, r_j^*\right) \in \kappa$, *one must satisfy the following:*

$$\begin{aligned}&\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o}\left[\frac{\partial f_i\left(Q_{ijk}^*\right)}{\partial Q_{ijk}} + \frac{\partial c_{ijk}\left(Q_{ijk}^*\right)}{\partial Q_{ijk}} - \rho_{ijk}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right) - \sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial \rho_{ihl}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)}{\partial Q_{ijk}} Q_{ihl}^*\right] \times \left(Q_{ijk} - Q_{ijk}^*\right)\\ &+\sum_{i=1}^{m}\left[\frac{\partial h_i\left(x_i^*\right)}{\partial x_i} - \sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial \rho_{ihl}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)}{\partial x_i} Q_{ihl}^*\right] \times \left(x_i - x_i^*\right)\\ &+\sum_{i=1}^{m}\left[\frac{\partial v_i\left(w_i^*\right)}{\partial w_i} + \left(\overline{\mu}\left(w_i^*, r_j^*\right) + \frac{w_i^*}{2m}\right) D_i - \sum_{h=1}^{n}\sum_{l=1}^{o}\frac{\partial \rho_{ihl}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)}{\partial w_i} Q_{ihl}^*\right] \times \left(w_i - w_i^*\right)\\ &+\sum_{j=1}^{n}\left[\frac{\partial \eta_j\left(y_j^*\right)}{\partial y_j}\right] \times \left(y_j - y_j^*\right)\\ &+\sum_{j=1}^{n}\left[\frac{\partial I_j\left(r_j^*\right)}{\partial r_j} + \left(\overline{\mu}\left(w_i^*, r_j^*\right) + \frac{r_j^*}{2n}\right) \times D_j\right] \times \left(r_j - r_j^*\right) \geq 0\end{aligned} \tag{18}$$

Proof. Variational inequality (18) is derived from the addition and simplification of variational inequalities (9) and (17). In the calculation process, the unit commission price $\ell\rho_{ijk}\left(Q_{ijk}^*, q_{ij}\left(x_i^*, y_j^*\right), \overline{\mu}\left(w_i^*, r_j^*\right)\right)$ charged by the platform operator to the service provider is eliminated. Finally, we get the equilibrium conditions of the entire PSSC network. □

5. Numerical Analysis

This part will discuss how members of the PSSC network decide their economic transaction activities through some numerical examples. This paper focuses on the impact of the sensitivity of the demand market to service quality, the relative importance of the service quality improvement level, the data empowerment cost, and the data security risk control investment on network equilibrium. The model adopts the modified projection algorithm and is solved by the MATLAB R2016a software package. The design calculation step is 0.05, and the termination condition is that the absolute value difference between two consecutive iterations is no more than 0.001. Because there are too many members in the network, to facilitate calculation and discussion, we assume that there are only two participants at each level in the network. The specific structure is shown in Figure 2.

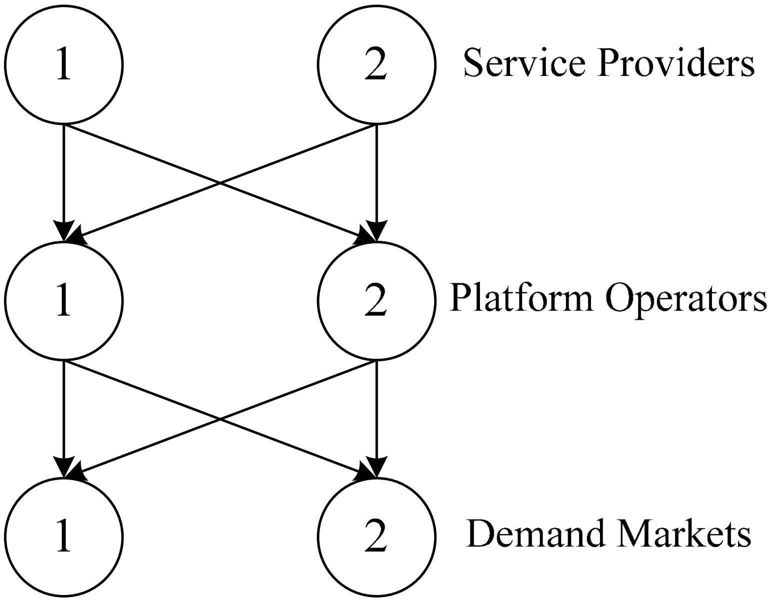


Figure 2. Network structure of the numerical example.

The functions and related parameters in the model mainly refer to the research of Nagurney et al. [48–50]. The specific settings are as follows.

The production cost functions of the service providers are:

$$f_1\left(Q_{1jk}\right) = 2 \times (Q_{111} + Q_{112} + Q_{121} + Q_{122})^2 + (Q_{111} + Q_{112} + Q_{121} + Q_{122}) \quad (19)$$

$$f_2\left(Q_{2jk}\right) = (Q_{211} + Q_{212} + Q_{221} + Q_{222})^2 + (Q_{211} + Q_{212} + Q_{221} + Q_{222}) \quad (20)$$

The transaction cost of platform operator 1 is:

$$c_{i1k}(Q_{i1k}) = 0.1Q_{i1k}^2 + 2 \quad (21)$$

The transaction cost of platform operator 2 is:

$$c_{i2k}(Q_{i2k}) = 0.2Q_{i2k}^2 + 1 \quad (22)$$

The demand price functions are:

$$\rho_{111} = -Q_{111} - 0.5Q_{112} + q_{11}(x_1, y_1) + 0.1(1 - \overline{\mu}) + 330 \quad (23)$$

$$\rho_{112} = -Q_{112} - 0.3Q_{111} + q_{11}(x_1, y_1) + 0.1(1 - \overline{\mu}) + 330 \quad (24)$$

$$\rho_{121} = -Q_{121} - 0.5Q_{122} + 0.5q_{12}(x_1, y_2) + 0.3(1 - \overline{\mu}) + 340 \quad (25)$$

$$\rho_{122} = -Q_{122} - 0.7Q_{121} + 0.5q_{12}(x_1, y_2) + 0.3(1 - \overline{\mu}) + 350 \quad (26)$$

$$\rho_{211} = -Q_{211} - 0.3Q_{212} + 0.3q_{21}(x_2, y_1) + 0.4(1 - \overline{\mu}) + 260 \quad (27)$$

$$\rho_{212} = -Q_{212} - 0.5Q_{211} + 0.8q_{21}(x_2, y_1) + 0.2(1 - \overline{\mu}) + 260 \quad (28)$$

$$\rho_{221} = -Q_{221} - 0.7Q_{222} + q_{22}(x_2, y_2) + 0.1(1 - \overline{\mu}) + 270 \quad (29)$$

$$\rho_{222} = -Q_{222} - 0.5Q_{221} + q_{22}(x_2, y_2) + 0.1(1 - \overline{\mu}) + 270 \quad (30)$$

The service quality improvement cost of service providers under data empowerment are:

$$h_1(x_1) = \alpha(x_1 - 1)^2 + \alpha x_1 \quad (31)$$

$$h_2(x_2) = \alpha(x_2 - 1)^2 + \alpha x_2 \quad (32)$$

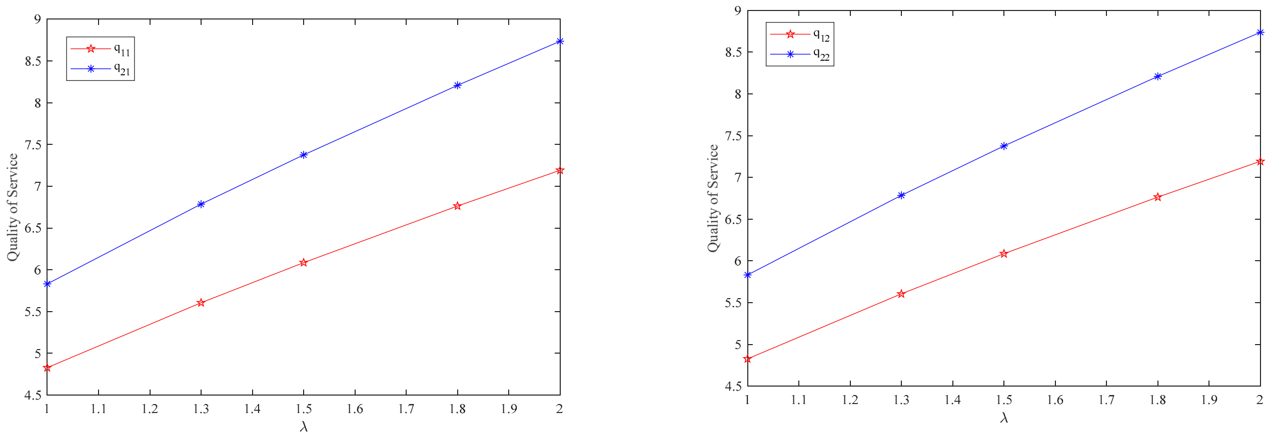
The service quality improvement cost of platform operators under data empowerment are:

$$\eta_1(y_1) = \beta(y_1 - 2)^2 + 2\beta y_1 \quad (33)$$

$$\eta_2(y_2) = \beta(y_2 - 2)^2 + 2\beta y_2 \quad (34)$$

When data security risks occur, the losses to service providers and platform operators are: $D_i^1 = 5$, $D_j^2 = 7$.

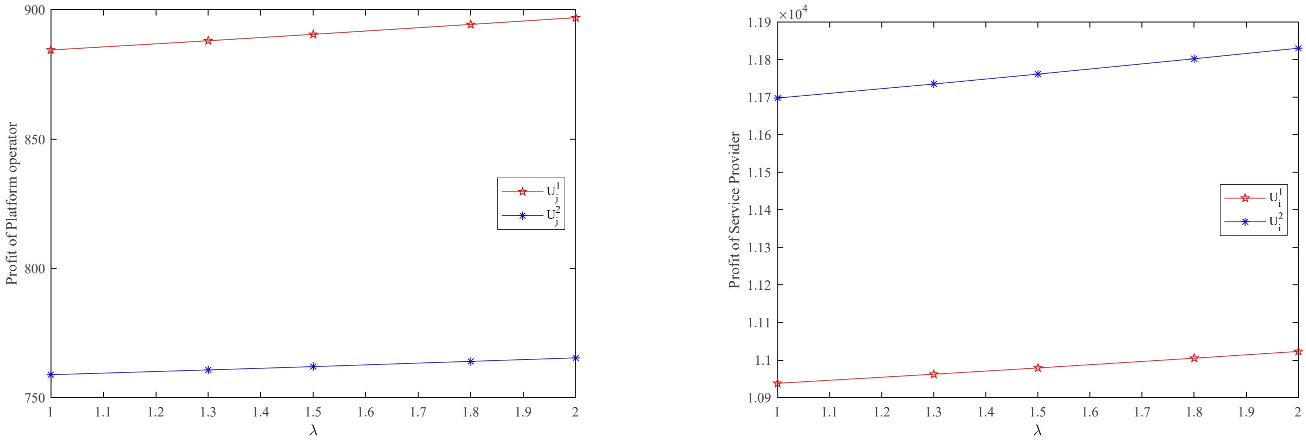
Example 1. *First, example 1 discusses the change of equilibrium conditions caused by the sensitivity of the demand market to service quality. We believe that the demand price function mainly reflects the sensitivity of the demand market to service quality. The parameters are set as:* $\theta = \frac{1}{3}$, $\alpha = 0.7$, $\beta = 0.5$, $\varphi_i = 0.7$, $\delta_j = 0.5$. *We assume* $\lambda = 1$, $\lambda = 1.3$, $\lambda = 1.5$, $\lambda = 1.8$, $\lambda = 2$. *After iteration and convergence, the relevant numerical changes in the equilibrium state are as shown in Figures 3 and 4.*



(**a**) (**b**)

Figure 3. Influence of service quality level sensitivity coefficient on service quality. Notes: (**a**) shows the service quality related to platform operator 1, where q_{11} represents the service quality output of service provider 1 and platform operator 1, and q_{21} represents the service quality output of service provider 2 and platform operator 1. (**b**) shows the service quality related to platform operator 2, where q_{12} represents the service quality output of service provider 1 and platform operator 2, and q_{22} represents the service quality output of service provider 2 and platform operator 2.

As can be seen from Figures 3 and 4, when the sensitivity coefficient of service quality level tends to be higher, the service quality, the profits of service providers, and the profits of platform operators are constantly improving. Considering the demand market is more sensitive to the change of service quality, consumers are more willing to pay higher purchase prices for high-quality services, to improve their consumption experience. In order to occupy a larger market share, service providers and platform operators are also more willing to invest costs to improve the overall service quality through data empowerment. However, in the process of data empowerment to improve service quality, service providers and platform operators have also increased cost investment, increasing the sales price of services in the demand market. According to the law of market supply and demand, the price reacts to the demand, reducing the service transaction volume in some demand markets with low sensitivity. However, the increase in income covers the increase in cost, which increases the profits of enterprises in the supply chain network. At the same time, consumers in the demand market also benefit from this process.



(**a**) (**b**)

Figure 4. Influence of service quality level sensitivity coefficient on the profits of service providers and platform operators. Notes: (**a**) shows the profits of platform operators, where ${U_j}^1$ represents the profits of platform operator 1 and ${U_j}^2$ represents the profits of platform operator 2. (**b**) shows the profits of service providers, where ${U_i}^1$ represents the profits of service provider 1 and ${U_i}^2$ represents the profits of service provider 2.

Example 2. *In Example 2, we explore the effect of changes in the relative importance of the level of service quality improvement on the equilibrium condition. The parameters are set as:* $\lambda = 1$, $\alpha = 0.7$, $\beta = 0.5$, $\varphi_i = 0.7$, $\delta_j = 0.5$. *We assume* $\theta = \frac{1}{4}$, $\theta = \frac{1}{3}$, $\theta = \frac{1}{2}$, $\theta = \frac{2}{3}$, $\theta = \frac{3}{4}$. *After iteration and convergence, the relevant numerical changes in the equilibrium state are as shown in Figures 5 and 6.*

Looking at Figures 5 and 6, with the increasing importance of the service quality improvement level of service providers, the service quality shows a "sudden" rise, and the profits of service providers and platform operators are also continuously improving. This is because when the service quality is more dependent on the service provider's improvement efforts, the service provider's input to the service quality can be more directly and effectively transformed into output. When the investment of platform operators remains unchanged, service providers can greatly improve the service quality with little effort, which makes service providers more willing to improve their data application level by increasing the investment cost of data empowerment, thus providing consumers with higher quality services and obtaining a sustainable competitive advantage in the demand market. By comparing and analyzing parts (a) and (b) of Figure 5, it can be found that platform operator 1 and platform operator 2 have the same level of service quality improvement through data empowerment, and neither of them is willing to increase the investment in data empowerment cost to improve consumers' service experience. This is because the revenue source of platform operators is to charge a fixed proportion of commission to service providers; hence, platform operators are only willing to invest a fixed data empowerment cost to ensure basic service quality (such as platform architecture services for transaction space and interaction rules). However, since the subjects and objects of data empowerment are investigated as a whole, and the service quality is produced by the cooperation between service providers and platform operators, even if the platform operators have free-riding behavior, their profits have also increased.

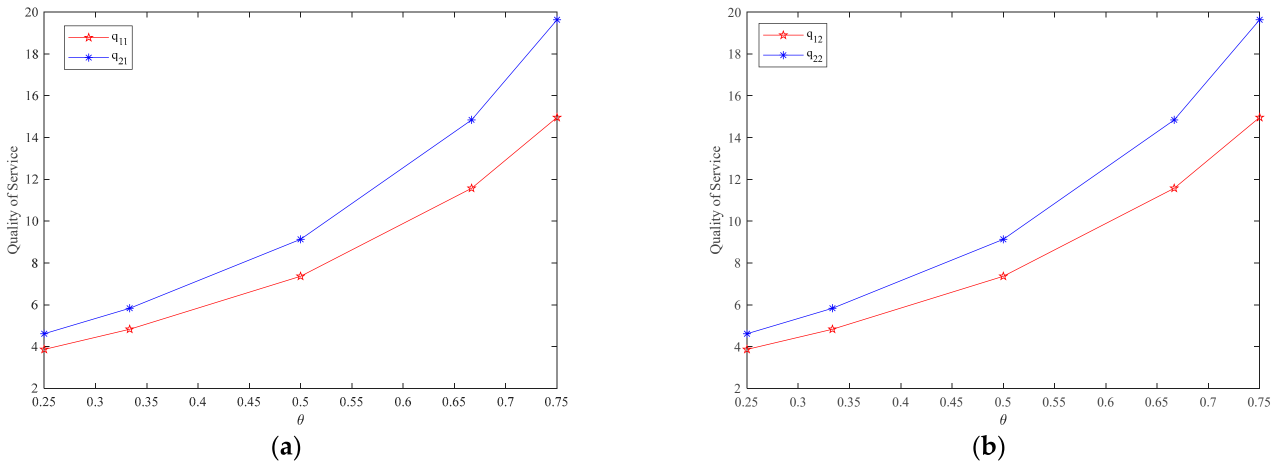


Figure 5. Influence of relative importance of service quality improvement level on service quality. Notes: (**a**) shows the service quality related to platform operator 1, where q_{11} represents the service quality output of service provider 1 and platform operator 1, and q_{21} represents the service quality output of service provider 2 and platform operator 1. (**b**) shows the service quality related to platform operator 2, where q_{12} represents the service quality output of service provider 1 and platform operator 2, and q_{22} represents the service quality output of service provider 2 and platform operator 2.

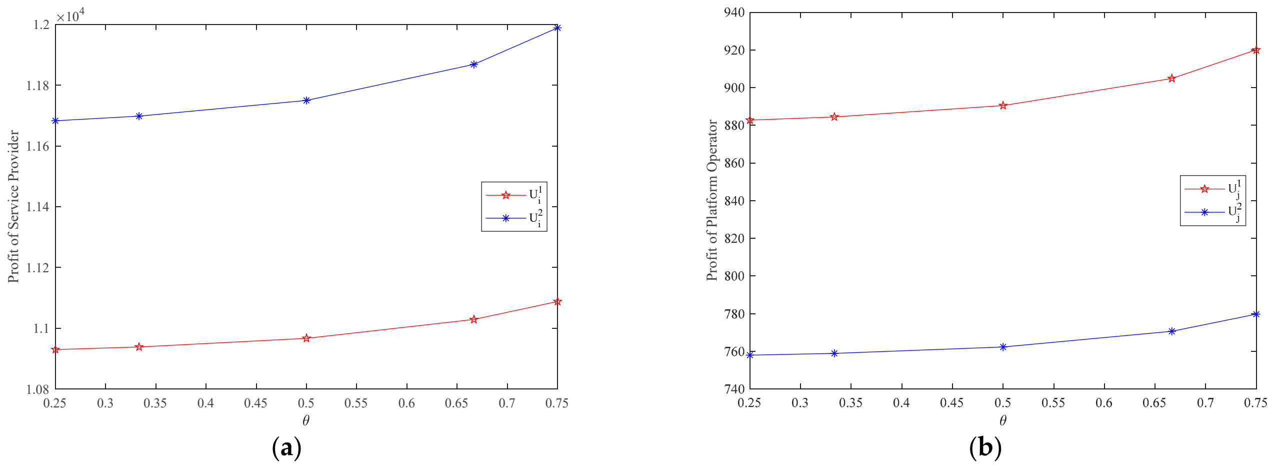


Figure 6. Influence of the relative importance of service quality improvement on the profits of service providers and platform operators. Notes: (**a**) shows the profits of service providers, where U_i^1 represents the profits of service provider 1 and U_i^2 represents the profits of service provider 2. (**b**) shows the profits of platform operators, where U_j^1 represents the profits of platform operator 1 and U_j^2 represents the profits of platform operator 2.

Example 3. *In this part, we discuss the impact of the change of data-enabling cost of service providers and platform operators on the network equilibrium state.*

The parameters are set as: $\lambda = 1$, $\theta = \frac{1}{3}$, $\beta = 0.5$, $\varphi_i = 0.7$, $\delta_j = 0.5$. We assume $\alpha = 0.1$, $\alpha = 0.3$, $\alpha = 0.5$, $\alpha = 0.7$, $\alpha = 0.9$. After iteration and convergence, the profits of all parties in the PSSC network are obtained, as shown in Table 2.

Table 2. Influence of service provider data empowerment to improve service quality cost influence coefficient on network balance.

α		0.1	0.3	0.5	0.7	0.9
U_i	${U_i}^1$	10,967.5895	10,949.5246	10,942.4763	10,938.2335	10,935.2496
	${U_i}^2$	11,744.1463	11,715.6762	11,704.5700	11,697.9008	11,693.2220
U_j	${U_j}^1$	888.8508	886.1406	885.0881	884.4550	884.0106
	${U_j}^2$	761.2064	759.7841	759.2214	758.8878	758.6543

Notes: U_i represents the profit of the service provider, where ${U_i}^1$ represents the profits of service provider 1 and ${U_i}^2$ represents the profits of service provider 2. U_j represents the profit of the platform operator, where ${U_j}^1$ represents the profits of platform operator 1 and ${U_j}^2$ represents the profits of platform operator 2. The symbols in the following tables represent the same meaning.

Similarly, the parameters are set as: $\lambda = 1$, $\theta = \frac{1}{3}$, $\alpha = 0.7$, $\varphi_i = 0.7$, $\delta_j = 0.5$. We assume $\beta = 0.1$, $\beta = 0.3$, $\beta = 0.5$, $\beta = 0.7$, $\beta = 0.9$. After iteration and convergence, the profit of each member of the network is obtained, as shown in Table 3.

Table 3. Influence of platform operator data empowerment to improve service quality cost influence coefficient on network balance.

β		0.1	0.3	0.5	0.7	0.9
U_i	${U_i}^1$	10,938.2335	10,938.2335	10,938.2335	10,938.2335	10,938.2335
	${U_i}^2$	11,697.9008	11,697.9008	11,697.9008	11,697.9008	11,697.9008
U_j	${U_j}^1$	885.6550	885.0550	884.4550	883.8550	883.2550
	${U_j}^2$	760.0878	759.4878	758.8878	758.2878	757.6878

As can be seen from Tables 2 and 3, when the influence coefficient of data empowerment and service quality cost of service providers is higher, the profits of service providers and platform operators have decreased. When the data empowerment of platform operators improves service quality and the cost influence coefficient is higher, the profits of service providers remain unchanged, and the profits of platform operators continue to decline. The higher the input cost of data empowerment to improve service quality, the lower the service quality of service providers' unit input and output, resulting in the decline of service transaction volume in the downstream demand market. High data empowerment input cost and low service transaction volume bring loss of profits, which is unfavorable to all parties in the supply chain. The platform operators only charge a fixed proportion of commission to the service providers. However, platform operators only charge a fixed proportion of commission to service providers. Therefore, the increase in data empowerment input cost of platform operators will not affect the profits of service providers.

Example 4. *Finally, through example 4, we discuss the impact of data security risk control investment of service providers and platform operators on the network equilibrium state.*

The parameters are set as: $\lambda = 1$, $\theta = \frac{1}{3}$, $\alpha = 0.7$, $\beta = 0.5$, $\delta_j = 0.5$. We assume $\varphi_i = 0.7$, $\varphi_i = 0.9$, $\varphi_i = 1.1$, $\varphi_i = 1.3$, $\varphi_i = 1.5$. After iteration and convergence, the impact of the change of service provider's data security risk control investment on the network equilibrium state is obtained, as shown in Table 4.

Table 4. Influence of service provider data security risk level impact coefficient on network balance.

φ_i		1	1.3	1.5	1.8	2
Q_{ijk}	Q_{111}	16.9218	16.9214	16.9213	16.9211	16.9211
	Q_{112}	16.9367	16.9370	16.9372	16.9375	16.9377
	Q_{121}	13.9130	13.9120	13.9115	13.9107	13.9103
	Q_{122}	22.2360	22.2359	22.2358	22.2356	22.2355
	Q_{211}	23.7780	23.7705	23.7691	23.7672	23.7661
	Q_{212}	24.3051	24.3055	24.3058	24.3061	24.3063
	Q_{221}	22.9835	22.9837	22.9838	22.9840	22.9841
	Q_{222}	22.9967	22.9970	22.9972	22.9974	22.9976
w_i	w_1	0.4166	0.4377	0.4509	0.4699	0.4822
	w_2	0.4590	0.4765	0.4872	0.5026	0.5124
r_j	r_1	0.2986	0.2989	0.3006	0.3047	0.3078
	r_2	0.2971	0.2947	0.2941	0.2948	0.2962
$\overline{\mu}$		0.3678	0.3769	0.3832	0.3930	0.3997
U_i	U_i^1	10,938.2335	10,937.9462	10,937.7578	10,937.4810	10,937.2985
	U_i^2	11,697.9008	11,697.5844	11,697.3760	11,697.0630	11,696.8562
U_j	U_j^1	884.4550	884.4175	884.3951	884.3599	884.3380
	U_j^2	758.8878	758.8517	758.8290	758,.7937	758.7714

Similarly, the parameters are set as: $\lambda = 1$, $\theta = \frac{1}{3}$, $\alpha = 0.7$, $\beta = 0.5$, $\varphi_i = 0.7$. We assume $\delta_j = 0.1$, $\delta_j = 0.3$, $\delta_j = 0.5$, $\delta_j = 0.7$, $\delta_j = 0.9$. After iteration and convergence, the impact of the change of platform operator's data security risk control investment on the network equilibrium state is obtained, as shown in Table 5.

Table 5. Influence of impact coefficient of data security risk level of platform operators on network balance.

δ_j		1	1.3	1.5	1.8	2
Q_{ijk}	Q_{111}	16.9218	16.9225	16.9229	16.9235	16.9239
	Q_{112}	16.9367	16.9370	16.9373	16.9375	16.9377
	Q_{121}	13.9130	13.9124	13.9121	13.9116	13.9113
	Q_{122}	22.2360	22.2350	22.2344	22.2336	22.2330
	Q_{211}	23.7728	23.7706	23.7694	23.7677	23.7666
	Q_{212}	24.3051	24.3055	24.3057	24.3060	24.3062
	Q_{221}	22.9835	22.9837	22.9839	22.9841	22.9842
	Q_{222}	22.9967	22.9969	22.9970	22.9971	22.9972
w_i	w_1	0.4166	0.4216	0.4247	0.4289	0.4315
	w_2	0.4590	0.4644	0.4677	0.4723	0.4751
r_j	r_1	0.2986	0.3373	0.3611	0.3937	0.4137
	r_2	0.2971	0.3371	0.3610	0.3937	0.4137
$\overline{\mu}$		0.3678	0.3901	0.4036	0.4221	0.4335
U_i	U_i^1	10,938.2335	10,937.8855	10,937.6719	10,937.3811	10,937.2018
	U_i^2	11,697.9008	11,697.4551	11,697.1834	11,696.8105	11,696.5818
U_j	U_j^1	884.4550	884.1766	884.0102	883.7798	883.6390
	U_j^2	758.8878	758.6001	758.4269	758.1883	758.0411

As can be seen from Tables 4 and 5, with the increase of the influence of the coefficient of data security risk level, that is, the continuous reduction of data risk control investment, the data security risk level of platform operators and service providers gradually increases, and the data security level of the whole PSSC network decreases. The profits of all member enterprises in the supply chain also gradually decrease. This is because as each member enterprise of the supply chain reduces the input of data risk control, it increases the probability of data security risk in the supply chain. Out of risk prevention awareness, consumers' willingness to pay for services decreases, and the service transaction price decreases, resulting in a decline of the overall profit of the whole supply chain network.

6. Discussion

First of all, when the service quality sensitivity coefficient tends to be higher, that is, the value proportion of service quality in services continues to increase, service providers and platform operators are more willing to increase data empowerment cost investment to improve the overall service quality (as shown in Figure 3), improve consumers' service experience, and increase their income in the process (see Figure 4). However, according to the law of market supply and demand, the increase in sales price will reduce the service transaction volume in some demand markets with low sensitivity to service quality, which is similar to the research conclusion of Nagurney and Wolf [52]. From this, it can be seen that the sensitivity of the demand market to service quality is an important factor affecting service sales. Therefore, member enterprises in the supply chain should use corresponding service quality publicity to improve consumers' value perception and trust. For example, refer to Büyükdağ et al. [56] and Guha et al. [57]—when consumers consume for the first time, service providers and platform operators can share the cost and provide a certain price discount ratio, so that consumers can experience high-quality services at a lower price, to win the trust of consumers and promote their secondary consumption. In reality, Didi Travel cooperated with WeChat in its development stage to improve its travel service quality through the analysis of Internet big data and the use of mobile terminals. It carried out a marketing subsidy strategy in its mature stage, continuously expanding its market share and merging with competitors to become an industry giant. This strategy can make up for the additional costs of data empowerment and publicity in the long run.

Secondly, with the increasing relative importance of the service quality improvement level of service providers, the input-output efficiency of service providers in terms of service quality continues to improve, which makes service providers more actively carry out service improvement and improvement activities through data empowerment to provide consumers with higher-quality services, which is similar to the research conclusion of Roels et al. [55] (as shown in Figure 5). However, comparing the two parts (a) and (b) in Figure 5, this study finds that the data-enabling input cost of platform operator 1 and platform operator 2 is the same, because the subject and object of data empowerment are investigated broadly, and the service quality is produced by the cooperation between service providers and platform operators. Therefore, platform operators may have free-riding behavior and are only willing to invest a fixed data empowerment cost to ensure the basic service quality. In this case, service providers should consider changing the profit distribution mode with platform operators and adopting a more reasonable revenue sharing strategy or cost-sharing strategy, so that platform operators can also actively participate in service quality improvement activities [31,58]. At the same time, platform operators should provide corresponding support to service providers and strengthen cooperation. Both sides should work together to obtain greater market satisfaction and profit space in the supply chain [59].

Thirdly, when the data empowerment of service providers improves service quality and the cost impact coefficient tends to be higher, the profits of member enterprises in the PSSC network decrease (see Table 2); when the data empowerment of platform operators improves service quality and the cost impact coefficient tends to be higher, the profits of platform operators decline, and the profits of service providers remain unchanged (for example, in Table 3, the profit of service provider 1 is maintained at 10,938.2335 and the profit of service provider 2 is maintained at 11,697.9008). It can be seen that higher data enabling improves service quality, and the investment cost is an important factor hindering service providers and platform operators from providing high-quality services. It is also one of the reasons why consumers find it difficult to experience high-quality and low-cost services in the demand market. Therefore, reducing the cost of data empowerment and improving service quality is beneficial to all PSSC parties. Realizing business improvement, efficiency improvement, and value creation through data and digital technology is regarded as one way to effectively reduce the cost of digital investment [33,35].

Finally, with the increase of the influence coefficient of data security risk level, that is, the continuous reduction of data risk control investment, the probability of data security risk in the supply chain increases significantly. Due to the awareness of risk prevention, consumers' willingness to pay for services will decrease, and the service transaction price and transaction quantity will decrease (as shown in Table 4, Q_{122} decreases from 22.2360 to 22.2330), resulting in a decline of the profits of each member enterprise of the supply chain, which is similar to the research conclusion of Qian et al. [60]. Therefore, each member enterprise of the supply chain should increase the investment in data security risk control, reduce the possibility of data security risks such as data leakage, and win consumers' trust. According to KPMG's prediction, China's expenditure on data security technology services is expected to reach CNY 10 billion by 2023. At the same time, the investment of a single member enterprise in data security risk control will affect its own data security level and the data security level of the whole PSSC network. Therefore, all member enterprises of the supply chain should strengthen cooperation to achieve win-win results.

7. Conclusions

This paper studies the network equilibrium of the PSSC in which multiple competing service providers provide services and sell them to consumers through multiple platform operators. The equilibrium conditions of service providers and platform operators are described by using variational inequality theory, the network equilibrium model of PSSC considering data empowerment is established, and the model is solved by modified projection algorithm. Through numerical examples, this paper discusses the impact of the service quality level sensitivity coefficient, the relative importance of the service quality improvement level, the cost impact coefficient of data enabling to improve service quality, and the data security risk level coefficient's impact on the decision-making and profit of PSSC network members.

Next, we will put forward specific suggestions for different subjects. First, data empowerment is always beneficial for service providers. Service providers should actively carry out service improvement and promotion activities through data empowerment and increase their income while meeting the consumers' needs for high service quality, to achieve a win-win situation. At the same time, service providers should drive platform operators to actively improve service quality through data empowerment and effective supply chain contract design, such as revenue-sharing contracts and cost-sharing contracts. Second, platform operators should take corresponding marketing measures to promote the sales of services so that the increased revenue can cover the expenditure of data enabling costs. In addition, platform operators should provide corresponding support to service providers and strengthen cooperation and coordination to ensure the sustainability of the PSSC [61]. Third, consumers in the demand market should change their consumption habits and be willing to pay for high-quality services. Furthermore, consumers should improve their awareness of data security risks. In this case, PSSC members have the power to invest in data enabling costs and data security risk control costs. Finally, for the whole PSSC network, the data security risk control investment of a single member is related to their interests and affects the data security level of the whole network. Therefore, all members should strengthen cooperation and work together to obtain greater market satisfaction.

Based on the abstract treatment of a complex decision-making relationship and the pertinence of research problems in the equilibrium model, this paper only analyzes the network structure of three-level PSSC composed of service providers, platform operators, and demand markets. We also simplify the relevant parameters. For example, the transaction cost only considers the single influencing factor of transaction quantity; at the same time, it is assumed that the transaction price is only affected by the service quantity, service quality, and data security risk. In addition, the budget constraints of data enabling investment in improving service quality and data security risk control are not considered. Therefore, based on this paper's theoretical framework and basic model, further research can consider evaluating and improving the network equilibrium of the PSSC under the above conditions.

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