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THE VALUE OF THE BLOCKCHAIN PLATFORM FOR SHIPPING LOGISTICS CONSIDERING THE PERCEIVED UTILITY OF CONSUMERS

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Abstract. Blockchain has been widely used to trace logistics information from sources to destinations in shipping logistics practices. Motivated by market practices, this study intends to discuss the potential application value of blockchain platforms in shipping logistics, considering the perceived utility of consumers. For this purpose, to investigate the shipping logistics supply chain (SLSC) of a shipping company (SC) and a freight forwarding company (FFC), in which FFC decides whether to introduce a blockchain platform and its introduction channel. Specifically, three channel models are considered: Model T (*i.e.*, traditional logistics supply chain channel), Model B (*i.e.*, FFCs applied a blockchain platform *via* a self-built platform channel), and Model J (*i.e.*, FFCs applied a blockchain platform *via* joining a third-party platform channel). Meanwhile, the Nash and Stackelberg game are used to characterize the companies' equilibrium outcomes under different power structures. By comparing these three modes, some interesting results are found: consumer perception of the level of service and privacy protection and consumer sensitivity to price has critical effects on the value of blockchain platforms. Results also show that the blockchain platform does not always motivate the members of the SLSC to become better. Whether the power structure is symmetrical or asymmetrical, FFC adopts Model B instead of Model J, in which the blockchain platform can help FFC increase profits, and the value of blockchain is significant. Moreover, the FFC can obtain at least approximately 78% more benefit when the power structure is symmetrical than asymmetrical. However, the value of blockchain platforms to SC is not necessarily significant. The value of the blockchain platform for SC is significant only in Model B with the power structure asymmetric. Therefore, the value of the blockchain platform in Model B with the power structure asymmetrical for both FFCs and SCs is significant, achieving a win-win situation. Also, an extensive numerical analysis showing the optimal channel strategy in the three models generated additional management insights.

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1. Introduction

With the increasingly frequent economic and trade exchanges between countries, shipping logistics have become an indispensable part of global trade exchanges [1], it transports 90% of the world's trade each year [2].

Keywords. Blockchain, Shipping logistics supply chain, Platform operations.

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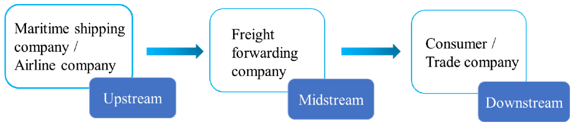

Figure 1. Shipping logistics industry chain. Source: Zhiyan Consulting Co., Ltd (www.abaogao.com).

Meanwhile, the shipping logistics industry prompted rapid changes in the direction of digitization, automation, and information [3, 4]. In this context, freight forwarder companies (FFCs) (*e.g.*, homeyun[1]) which are the central link in shipping logistics, have adopted platform operations to improve their shipping logistics efficiency to cope with market changes. Platform operation can provide consumers with one-stop shipping logistics services and enable consumers to query their logistics information quickly and efficiently [5]. However, consumers get detailed logistics information about goods in transit on the platform by the means of documents uploaded by FFCs. So, several problems with the disclosed logistics information remained: (1) logistics information may be fake or delayed because these logistics documents (*e.g.*, letters of credit and bills of lading) are easily forged or lost [6, 7]; (2) the authenticity of logistics information needs to be further verified because logistics companies may tamper with cargo tracking information [4, 8]; (3) consumers are prone to leakage of private information in the process of sending or receiving cargo; and (4) for consumers, the tracking and tracing of goods and the detailed logistics route information are not clear [6, 9]. In addition, if the goods are damaged in transit, it would be difficult to identify the responsible party due to a lack of tracking information.

To solve these above-mentioned problems, the FFC plans to introduce blockchain platform to shipping logistics supply chain (SLSC). FFCs are the midstream in the SLSC which can connect consumers and shipping companies (SCs) [10], as shown in Figure 1. FFCs hope that the application of blockchain platforms through digitalizing and easing paperwork, tracking and tracing, and customs clearance and management [8]. Blockchain is a distributed network with many blocks that store multiple copies of nodes' encrypted transaction data that are transparent, trusted, tamper-proof, traceable, and decentralized [11]. Any network user can easily access these blocks and verify the transactions data but cannot change the data. Such a distributed and encrypted data structure can ensure the creation of timely and secure logistics transaction records during the logistics transportation process, providing complete and authentic logistics data [12]. Furthermore, by assigning corresponding keys to different users, logistics data in the blockchain can be shared at a low cost, thus improving the transparency of logistics information. Thus, the application of the blockchain platform supported realizes the digitization of logistics information and real-time tracking of cargo, improving the efficiency of customs declaration and quarantine inspection [4, 13].

Being aware of the disruptive nature of blockchain platforms, in real-world practice, many logistics companies have made attempts to apply blockchain platforms. For example, in 2018, Maersk and IBM collaborated to develop a blockchain platform (called TradeLens[2], see Fig. 2) to provide digital logistics solutions for SLSC. Many FFCs are also trying to develop blockchain platforms for shipping logistics businesses (*e.g.*, CargoX[3], see Fig. 3) to be competitive in the market. Sinotrans Logistics is committed to building a world-class smart logistics platform and has been studying how blockchain technology can be applied to the logistics industry since 2017. The use of blockchain platforms can undoubtedly bring consumers a better consumer experience. However, forFFCs, the huge blockchain costs associated with using a blockchain platform (*i.e.*, the big unit operating costs of a platform based on blockchain technology [9]) may create an investment risk that could negatively impact FFCs. Moreover, it is noteworthy whether the application of blockchain platforms will affect the current market power structure. Therefore, for FFC who want to introduce the blockchain platform, the

[1] http://www.homeyun.com/.
[2] https://www.tradelens.com/.
[3] https://cargox.io/.

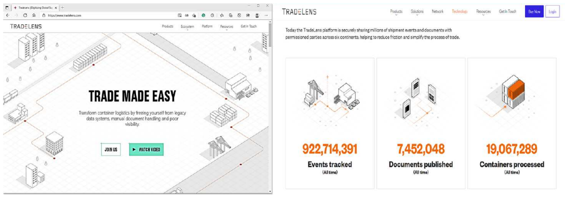

FIGURE 2. The screen capture of the "TradeLens" platform.

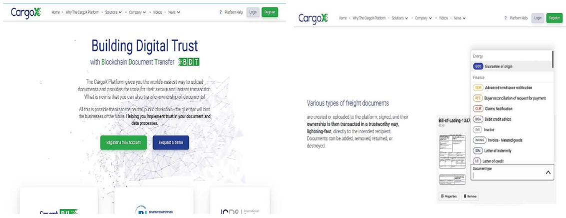

FIGURE 3. The screen capture of the "CargoX" platform.

question of how the blockchain platform will affect their application remains unclear. Against this background, the first interesting tricky question is: Are FFC introducing blockchain platforms to enhance the consumer experience demonstrating the value of blockchain platforms? If the application of a blockchain platform changes the power structure of the market, is it beneficial to the SLSC?

In the current market environment, it is worth noting that many companies face channel structure selection decisions on how to join the platform application [14]: one is the self-built platforms channel. That is, the company can provide services through self-built platforms, interacts with consumers directly, and can also attract other members to join the platform to provide services together, such as JD.com; the other is joined third-party platforms channel. That is, the company joins a third-party platform to provide services by paying a commission fee to the third-party platform for each transaction service, such as Amazon and Taobao. For example, Amazon levies commission rates between 8% and 15% on merchants selling goods on the platform. So, companies around the world are exploring how to use new technologies like blockchain in a better channel to optimize their supply chains [15,16]. Therefore, considering two different channel structures, the second question is naturally: Which is the best channel structure for FFCs to introduce the blockchain platform to maximize the value of the blockchain platform? Which channel structure is more beneficial to SLSC?

Based on the motivations above, this paper conducts a theoretical model focusing on the value of blockchain platforms where FFCs provide services through different channels in different power structure scenarios. This paper aims try to solve the following questions:

(1) Considering the perceived utility of consumers, will introducing blockchain platforms by FFCs bring value compared to traditional logistics supply chains? Will it bring more benefits to the FFC, the SC, and consumers?
(2) For FFCs, which channel model do FFCs adopt to optimize value of the blockchain platform? a self-built platform channel? Or join a third-party platform channel?
(3) Consider that the application of blockchain platforms may change the current power structure of SLSC. How does the power structure affect FFCs' channel model preferences?

First, discuss the three channel models that FFCs can adopt: (1) Model T (*i.e.*, traditional logistics supply chain channel), (2) Model B (*i.e.*, FFCs applied a blockchain platform *via* a self-built platform channel), (3) Model J (*i.e.*, FFCs applied a blockchain platform *via* joining a third-party platform channel). Then, derive

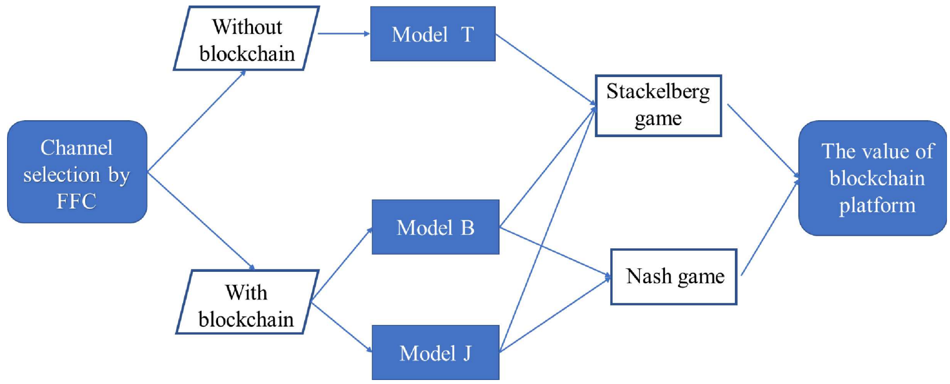

Figure 4. Research framework.

equilibrium solutions under different channel models under different power structures (*i.e.*, using the Nash and Stackelberg game to describe the equilibrium outcomes), and analyze how the optimal decisions are affected by the relevant parameters. Finally, the differences in the three channel models under the influence of different power structures are compared to obtain the optimal channel model strategy for FFCs to maximize the value of the blockchain platform. The research framework of this paper is shown in Figure 4.

The main contribution of this paper includes three ways: (1) Existing research on blockchain in supply chain management applications has done excellent work. However, research on SLSCs has only emerged in recent years and is still in the early stages. In particular, less attention has been paid to discussing how FFCs are introducing blockchain platforms from the perspective of FFCs. Therefore, this paper provides a theoretical study to discuss how FFCs introduce blockchain platforms to demonstrate the value of blockchain platforms. This research can provide an investment decision reference for FFCs to invest in blockchain platforms. (2) There is quite a lot of research on the characteristics of blockchain technology, including traceability and transparency [17], etc. However, few studies have previously analyzed how the perceived utility of consumers brough by blockchain technology affects FFCs' channel preference for applying blockchain platforms. It is an important factor from an economic point of view. Therefore, this paper provides a strategic analysis of the channel selection for FFCs when applying blockchain platforms with considering consumer' perceived utility. It is helpful for FFCs to seek controllable conditions to achieve optimal and provides suggestions for shipping logistics business decisions. (3) Consider the possibility that the application of the blockchain platform will change the original market power structure. This paper explores the impact of different power structures on the channel choice preference of FFCs introducing blockchain platforms and provides a new angle for analyzing the value of blockchain platforms. These endow the research with both practical and theoretical significance.

This paper organizes as follows. Section 2 presents the related literature. Section 3 presents the problem description, notation, and assumptions. Section 4 describes three channel models, namely Model T, Model B, and Model J. Section 5 presents the game-theoretical analysis to explore the potential value of the blockchain platform by comparing three models in different power structure scenarios. Section 6 presents a sensitivity analysis to illustrate the choice of channel strategy. Section 7 summarizes with a discussion of management insights and research extensions. For more clarity, Appendix A list all proofs and technical details.

2. Literature review

This paper is relevant to three topics: blockchain application, shipping logistics supply chain, and platform operations. By examining the relevant literature, it is noted this study how fills the gaps of previous studies.

2.1. Blockchain application

As a new technology, blockchain can realize economic transactions between related parties without the trust of third parties [18]. Therefore, blockchain is widely used in many industries, such as the chemical industry [19], the medical industry [20], and the fashion industry [9]. Blockchain technology is sought after by various industries mainly due to two advantages: one is to provide real-time information, which overcomes the problems of information insecurity and mistrust [13]. The other is to achieve the traceability of supply chain products [17]. For instance, Wal-Mart and IBM jointly launched a tracking system of the food supply chain to ensure food safety based on blockchain [14]. Blockchain is widely used in the supply chain and has become a research hotspot. For example, Shen *et al.* [21] studied second-hand platforms that use blockchain technology to disclose the value of second-hand product quality in the supply chain. Choi [9] studied the value of the diamond certification platform under the application of blockchain technology. Liu *et al.* [15] examined the role blockchain plays in the imported fresh food supply chain and considered the impact of risk attitudes on supply chain decisions. Cao *et al.* [22] examined how using blockchain technology in cross-border supply chains prevents less sustainable products from entering the incumbent market. Although there have been many studies on the application of blockchain to the supply chain, the theoretical understanding of the value of blockchain platforms to the SLSC is limited. Furthermore, only a few recent studies have addressed this topic *e.g.*, Yu *et al.* [12], Choi [9], Choi *et al.* [23], and Niu *et al.* [20]. In addition, the application of blockchain technology might change the current power structure of the SLSC. However, few studies have analyzed the value of blockchain platforms in this scenario. To fill this gap, motivated by Choi [9], this paper examine the value of blockchain platforms in the SLSC, and also consider the value in the case that blockchain platforms change the power structure of the SLSC.

2.2. Shipping logistics supply chain

In the past, most studies focused on a link in the shipping logistics supply chain, such as freight forwarders [24], maritime shipping [4]. Wang *et al.* [2] discussed the service purchase behavior of forwarders in the shipping supply chain and whether the shipping company chooses to enter the downstream cargo packaging market. Li and Zhang [25] considered the capacity-sharing between the two forwarders in a shipping system. Song *et al.* [26] studied that liner companies discuss two freight forwarding strategies through the principal-agent model, involving freight forwarders and non-vessel-operating common carriers in the maritime cargo service chain. In recent years, scholars have begun to pay attention to the application of blockchain in the logistics supply chain. Scholars have pointed out that the implementation of blockchain platforms can realize the efficient conversion of data flows between stakeholders in the logistics supply chain, thereby improving the efficiency of the logistics supply chain [13]. Ahmad *et al.* [6] discussed the potential role of blockchain technology in transforming port logistics operations and services and proposed an architecture and deployment scheme for blockchain technology-based port logistics to automate logistics operations. However, few studies investigated the impact on SLSC when specific members of the SLSC adopt the blockchain platform. Therefore, the core issue of this paper is to explore the impact on the SLSC when FFCs adopt a blockchain platform.

2.3. Platform operations

Platforms play a critical role in all kinds of industries, and the issue of platform operation is always a research hotspot. Choi and He [27] studied the fashion rental platform operations with the considerations of peer-to-peer collaborative consumption. They proved that the presence of peer-to-peer collaborative consumption is beneficial to the fashion brand and the consumers. Choi *et al.* [28] investigated the platform operations for managing food product leftovers. They found that proper using the platform can achieve all wins and enhance social welfare. Zeng *et al.* [29] focused on an open platform for case studies and integrated 25 cases to investigate the adoption of information systems by organizations in the maritime supply chain. Barenji *et al.* [30] proposed an intelligent platform for e-commerce logistics services. With the advent of the platform era, many scholars have started to study channel strategy selection when applying platforms [31]. Wang *et al.* [32] analyzed the strategic choice of how manufacturers join online channels to expand existing brick-and-mortar retail channels, *i.e.*, choosing direct sales channels or third-party e-commerce platform channels. Niu *et al.* [33] considered a fast-food restaurant that sells food both online and in brick-and-mortar stores and discussed the strategic choice of whether the fast-food restaurant should use platform logistics or choose its self-operated logistics to deliver online orders. Cao *et al.* [31] studied whether remanufacturers enter the platform in the context of relatively high online return rates and whether third-party stores on e-commerce platforms need to use third-party logistics. The study found that whether remanufacturers should enter the platform depends not only on the annual service fee charged by the platform but also on the carbon tax price set by the government. In addition, the combination of blockchain technology and platform operations has aroused the interest of many scholars. Li *et al.* [34] proposed a logistics financial platform base on the application of blockchain technology to solve the problem of financing difficulties for small and medium-sized enterprises, thereby promoting the development of e-commerce. The above papers have studied the platform channel strategy from different aspects, but less literature discussing the platform channel strategy selection under the background of the combination of blockchain technology and SLSC. Therefore, this paper investigates the issue of strategy channel selection when FFCs adopt blockchain platforms in the SLSC, which is different from the above-mentioned papers.

2.4. Research gaps

In addition to these literature reviews, Table 1 shown the summary of relevant works highlighting the research gaps of this paper. Most papers consider the integration of blockchain into supply chains from multiple aspects, yet, there is still a lack of understanding of the value of blockchain platforms in SLSC with different channels, as well as considering the value of blockchain platforms under different power structure in the SLSC. Thus, the research gaps of this paper relative to the related research are summarized in two aspects. Firstly, this paper analyzes the value of blockchain platforms when FFCs in the SLSC introduce blockchain platforms in different channel structures with considering consumers' perceived utility. It also examines which channels are optimal for FFCs to apply blockchain platforms to benefit the SLSC. The results show that consumer perception of the level of service and privacy protection and consumer sensitivity to price has critical effects on the value of blockchain platforms. The results also show that the value of the blockchain platform will not be significant in every channel. Secondly, considering the scenario where applying blockchain technology could change the power structure of the SLSC, this paper analyzes the proposed three channel models in the different power structures of the SLSC by the game-theoretical (*i.e.*, Stackelberg game and Nash game). The results find that, whether the power structure is symmetrical or asymmetrical, FFC adopts Model B instead of Model J, in which the blockchain platform can help FFC increase profits, and the value of blockchain is significant. Moreover, the FFC can obtain greater when power structure is symmetrically rather than that asymmetrical. However, the value of blockchain platforms to SC is not necessarily significant. The value of the blockchain platform for SC is significant only in Model B with the power structure asymmetric. Therefore, the value of the blockchain platform in Model B with the power structure asymmetrical for both FFCs and SCs is significant, achieving a win–win situation. Therefore, this study can complement the literature on the decision-making of introducing blockchain platforms in the SLSC and provide new management implications for blockchain applications.

3. Problem description, notation, and assumptions

The problem description, notation, and assumptions are illustrated in this section:

3.1. Problem description

This paper constructs an SLSC consisting of an SC and an FFC. FFCs are responsible for providing logistics services to consumers. The SCs provide shipping space for goods and completes the transportation of the goods. At present, FFCs can choose to maintain the traditional shipping logistics channels to provide services to consumers, or they can decide whether to introduce the blockchain platform for shipping logistics to improve the level of service to consumers. On the blockchain platform in which a new shipping logistics business is generated, the shipping logistics information will be written into a distributed ledger and transmitted to other blockchain

Table 1. Comparison between this article and related literature.

Paper	Power structure		Consumer's perception utility	Channel		Supply chain	Block-chain
	Stackel-berg	Nash		Self-built	Third-party		
Yang *et al.* [4]						✓	✓
Zhong *et al.* [8]	✓					✓	✓
Choi [9]	✓		✓		✓	✓	✓
Yu *et al.* [12]						✓	✓
Liu *et al.* [15]	✓		✓			✓	✓
Shen *et al.* [21]	✓					✓	✓
Cao *et al.* [22]	✓					✓	✓
Niu *et al.* [20]	✓		✓			✓	✓
Chaab and Demirag [35]	✓	✓	✓			✓	
Choi *et al.* [16]		✓				✓	✓
Niu *et al.* [33]			✓	✓	✓	✓	✓
Pal *et al.* [36]	✓	✓				✓	
This paper	✓	✓	✓	✓	✓	✓	✓

nodes for simultaneous verification. Once the authenticity of shipping logistics information is verified, a new block will be formed. The implementation process of the shipping logistics business on the blockchain platform strictly follows the terms of the smart contract. Once the smart contract is triggered, the shipping logistics business can be executed. Decentralized verification and timestamp on blockchain platforms can effectively ensure the authenticity of shipping logistics information, and complex encryption mechanisms can avoid the risk of shipping logistics information leakage [8]. Therefore, the application of a blockchain platform can provide consumers with a better level of service, thus improving consumers' perceived utility. The perceived utility of the consumer is a key factor in the smooth operation of the SLSC.

Generally speaking, there are two channel structures for FFCs to introduce blockchain platforms: (1) The first is a self-built platform channel structure in which the FFC provides services directly to consumers and receives a commission fee from other members who use it. (2) The second one is joining a third-party platform channel structure in which the FFC provides services indirectly to consumers by paying a commission fee to it. Thus, to explore the best channel structure for FFCs to introduce blockchain platforms to maximize the value of the blockchain platform, this paper considers three channel models, (1) Model T; (2) Model B and (3) Model J.

3.2. Notation

To define the model, refer to Saxena *et al.* [17], Dey *et al.* [37], related notations along with the units are summarized in Table 2.

3.3. Assumptions

According to the above problem description and to facilitate the modeling solution, this paper combining relevant theories and practical situations, puts forward the basic assumptions.

(1) The SC and FFC studied in this paper are risk neutral and rational, aiming to maximize their benefit.
(2) Blockchain technology can record all shipping logistics transaction data on the blockchain platform, and each participant can access the transaction records and logistics information of the shipping logistics business while protecting the privacy information of each participant. The application of a blockchain platform can improve the transparency and traceability of the shipping logistics chain and reflect the authenticity of

TABLE 2. Major notations used in this paper.

Notations	Meaning
α	The market demand base reflecting the potential market demand size of consumers ($\alpha > 0$)
p	The total freight in market ($/W/M)
θ	The logistics information service level
βt	The negative effect of taking time in checking and evaluating logistics information
γ	The "trust factor" ($0 < \gamma < 1$)
w	The ocean freight is supplied by the SC ($/W/M)
ρ	The protection level of consumers' personal privacy information
λ	The influence coefficient of the negative effect of consumers' personal privacy information leak risk ($0 < \lambda < 1$)
ε	The price sensitivity coefficient of consumers ($\varepsilon > 0$)
c_s	The unit operating cost for the SC ($/W/M)
c_f	The unit operating cost for the FFC ($/W/M)
c_g	The transaction cost ($/unit transaction)
c_b	The blockchain cost ($/unit transaction)
e	The commission fee ($/unit transaction)
c_m	The unit operating cost of the third-party platform ($/unit transaction)
φ	The cost optimization coefficient
x	The FFC supplies the handling charge to the third-party platform ($/W/M)

logistics information [20]. Consumers can check the logistics progress and location of goods in real-time. Therefore, this paper assumes that consumers have preferences for logistics information, *i.e.*, consumers are willing to pay for transparent, authentic, and safe logistics information.

(3) To simplify the model reasonably, without loss of generality, this paper assumes the SC sells shipping space to the FFC with ocean freight w, and the FFC based on ocean freight and handling charge fees incurred for provided services to form the total freight p to consumers. The FFC's costs include: (a) the unit operating cost is c_f and (b) transaction costs c_g for logistics business deals with SCs. The SC's costs include: (a) the SC's unit operating cost is c_s and (b) transaction costs c_g for logistics business deals with FFCs.

(4) According to the principle of increasing marginal cost, this paper assumes that the input services cost of shipping logistics information services provided by FFCs to consumers is a quadratic function of service level, which is consistent with the convex function characteristics. Refer to Fu *et al.* [38] and Liu *et al.* [39], assumed that the FFC invests in services costs of logistics information services is $k\theta^2/2$, where k is the fixed cost coefficient of the FFC investment in logistics information services to improve services level, and θ $(0 < \theta < 1)$ represents the services level of the FFC invests in logistics information services. It indicates that when the service level increases, the service input cost also increases. The higher the level of logistics information service, the greater the increase in service input cost.

3.4. Demand function

Although the nonlinear demand function can better describe real-life consumer purchasing behavior, to simplify the model calculation, drawing on the design of the demand function by Pal *et al.* [36], Fu *et al.* [38] and Gao *et al.* [40], this paper assumes that the demand function of the shipping logistics market is a linear function that approximates the sales price. Normally, the demand function of shipping logistics is affected by many factors, refer to many previous studies, *e.g.*, Fu *et al.* [38], Huang *et al.* [14], Chaab and Demirag [35], etc., a linear demand function is assumed as follows.

In the traditional logistics business, factors affecting the market demand for shipping logistics include: (1) The total freight p. (2) The FFC provides the logistics information service level θ to consumers. Owing to the potential doubt by consumers towards the logistics information provided, then the logistics information service level θ can yield the utility $\theta\gamma$ to the consumers, where $0 < \gamma < 1$ is a "trust factor" a larger γ represents a higher level of trust [41]. (3) The authenticity of logistics information. Suppose that the negative effect of the consumers takes the time in checking and evaluating logistics information is βt, and the time t is scaled by the coefficients β [9]. (4) Consumers' personal privacy information. The consumers' personal privacy information

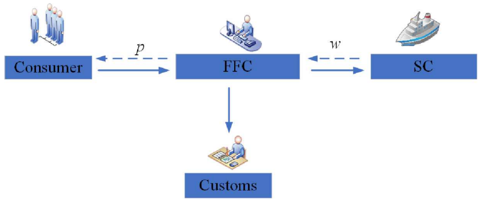

FIGURE 5. The logistics supply chain structures in Model T.

leak risk is $(1-\rho)\lambda$, ρ indicates the protection level of consumers' personal privacy information. λ is the influence coefficient of the negative effect of consumers' personal privacy information leak risk. Thus, demand function by equation (1) is formulated. (The subscript 1 represents the scenario of traditional logistics business.):

$$D_1 = \alpha - \beta t - \varepsilon p - (1-\rho)\lambda + \theta\gamma, \tag{1}$$

where α is the market demand base reflecting the potential market demand size of consumers in the shipping logistics market. ε is the price sensitivity coefficient of consumers, reflecting the impact of the total freight of goods on consumer demand.

In the scenario of blockchain platform applications, it brings a different consumer experience to consumers. The factors affecting the market demand for shipping logistics include: (1) the blockchain platform will provide a digital authentication and verification process of shipping logistics information based on blockchain technology for each piece of goods transported. A logistical record will be created in the platform for each shipment and will be published online in a permanent and verifiable manner. Therefore, consumers can improve their trust in the logistics information service provided by the platform. Here, consumers have higher trust γ in the logistics information service θ provided by the blockchain platform and normalize the coefficient γ to 1 [40]. That is, the logistics information service θ can bring the utility of θ to the consumers. (2) Blockchain platform ensure the authenticity of logistics information and resist tampering. So, the time cost for consumers to identify the logistics information authenticity can reduce to zero. (3) Blockchain platform can well protect consumer privacy information so that the risk of consumer privacy information disclosure is zero. Thus, the protection level of consumers' personal privacy information is ρ. Thus, a linear demand function by equation (2) is formulated. (Use subscript 2 to represents scenario of blockchain platform applications.):

$$D_2 = \alpha - \varepsilon p + \rho + \theta. \tag{2}$$

4. THE MODEL

Accordingly, the profit functions of the members in the SLSC can be described as the following:

4.1. Mode T (traditional logistics supply chain channel)

This section considers a case where the consumer wants to send the goods abroad and entrusts the goods to FFC, which is the service provider in SLSC. After receiving the consumer's order, the FFC will consult the SC's quotation and choose an appropriate SC for cooperation. The FFC needs to prepare the bill of lading documents required by the shipping logistics for the consumers and handle customs inspections and other related matters [2]. The structure of the SLSC as Figure 5.

Therefore, the FFC's and the MSC's profits are:

$$\pi_f^{\mathrm{T}}(p) = (p - w - c_f - c_g)D_1 - k\theta^2/2, \tag{3}$$

$$\pi_s^{\mathrm{T}}(w) = (w - c_s - c_g)D_1. \tag{4}$$

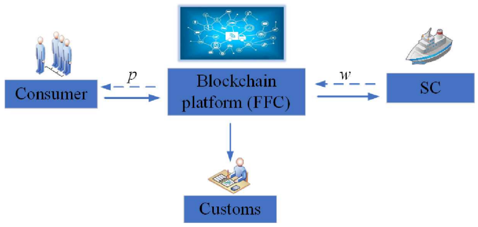

FIGURE 6. The logistics chain structure in Model B.

4.2. Model B (FFCs applied a blockchain platform *via* a self-built platform channel)

This section considers a case where the consumer sends cargo abroad through the FFC's self-built blockchain platform, which acts as the service provider in SLSC. The structure of the SLSC is shown in Figure 6. This way, the blockchain platform replaces the FFC to provide services to consumers and other supply chain members. The application of the blockchain platform can reduce the unit operation cost, and the cost optimization coefficient is φ [42]. The blockchain platform can intelligently match appropriate SCs to reach logistics business transactions, so the transaction costs are zero.

Hence, the FFC's and the MSC's profits are:

$$\pi_f^{\mathrm{B}} = (p - w - c_b - \varphi c_f + e_s)D_2 - k\theta^2/2, \tag{5}$$

$$\pi_s^{\mathrm{B}} = (w - \varphi c_s - e_s)D_2. \tag{6}$$

4.3. Model J (FFCs applied a blockchain platform *via* joining a third-party platform channel)

This section considers a case where the FFC provides service to consumer by joining a third-party blockchain platform and must pay a commission fee $e_i (i = s, f)$ to it for each transaction. Similarly, the SC provides the ocean freight to the platform at a unit price w and pay a commission fee e_s for each transaction. The FFC provides the handling charge fees x to the platform and pay a commission fee e_f for each transaction. The blockchain platform charges commission fee $e_i (i = s, f)$ in each transaction and provides consumers with a total freight p. The platform operation generates unit operating cost c_m. It is worth noting that under Model J, the SLSC structure is longer than that under Model B and Model T, as shown in Figure 7. Moreover, the profits of platform, FFC and SC are:

$$\pi_m^{\mathrm{J}} = (p - x - w - c_b - c_m + e_f + e_s)D_2 - k\theta^2/2, \tag{7}$$

$$\pi_f^{\mathrm{J}} = (x - \varphi c_f - e_f)D_2, \tag{8}$$

$$\pi_s^{\mathrm{J}} = (w - c_s - e_s)D_2. \tag{9}$$

5. DECISIONS ANALYSIS

5.1. Stackelberg game

In the current structure of the SLSC, the SC acts as the leader, and the FFC plays a follow-up role. The Stackelberg game applies to this situation. The SC first determines the ocean freight w, based on the perceived total freight p of that the FFC may set. The FFC then determines the total freight p based on the ocean freight w to maximize its profit. To avoid confusion, a superscript "S" is added to denote the corresponding notation in Stackelberg game in Section 5.1. Propositions 5.1–5.3 gives the equilibrium decisions resulting from the backward induction process.

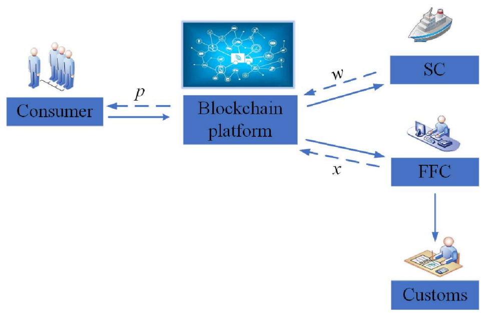

FIGURE 7. The SLSC structure in Model J.

5.1.1. Stackelberg game of Model T

Proposition 5.1. *The equilibrium results of Model T obtained by the Stackelberg game analysis are as follows.*

$$D_1^{\mathrm{S-T}*} = (\alpha - \beta t + \theta\gamma + \lambda(\rho - 1) - \varepsilon(c_f + 2c_g + c_s))/4, \tag{10}$$

$$p^{\mathrm{S-T}*} = 3(\alpha - \beta t + \theta\gamma + \lambda(\rho - 1)) + \varepsilon(c_f + 2c_g + c_s)/4\varepsilon, \tag{11}$$

$$w^{\mathrm{S-T}*} = (\alpha - \beta t + \theta\gamma + \lambda(\rho - 1) + \varepsilon(c_s - c_f))/2\varepsilon, \tag{12}$$

$$\pi_f^{\mathrm{S-T}*} = \Big((\alpha - \beta t + \theta\gamma + \lambda(\rho - 1) - \varepsilon(c_f + 2c_g + c_s))^2 - 8k\varepsilon\theta^2\Big)/16\varepsilon, \tag{13}$$

$$\pi_s^{\mathrm{S-T}*} = (\alpha - \beta t + \theta\gamma + \lambda(\rho - 1) - \varepsilon(c_f + 2c_g + c_s))^2/8\varepsilon. \tag{14}$$

Proposition 5.2. $D_1^{\mathrm{S-T}*}$, $p^{\mathrm{S-T}*}$, $w^{\mathrm{S-T}*}$ *and* $\pi_s^{\mathrm{S-T}*}$ *are (i) increasing in* θ, ρ, γ*; (ii) decreasing in* β, ε *and* λ*; (iii) when* $\theta > \theta_1$, $\theta_1 = \gamma(\alpha - \beta t - \lambda + \lambda\rho - \varepsilon(c_f + 2c_g + c_s))/(8k\varepsilon - \gamma^2)$, $\pi_f^{\mathrm{S-T}*}$ *is increasing in* θ, ρ, γ *and decreasing in* β, ε *and* λ*; (iv) and the profit of the SC* $\pi_s^{\mathrm{S-T}*}$ *is higher than that of the FFC* $\pi_f^{\mathrm{S-T}*}$.

Proposition 5.2 states some structural properties about the optimal demand, optimal total freight, optimal ocean freight, and optimal profit. A larger ρ, θ, γ leads to a higher optimal demand, optimal total freight, optimal ocean freight, and a larger optimal profit for the SC. For β, λ, ε, a larger β, λ, ε also yields a lower optimal demand, optimal total freight, optimal ocean freight, and a smaller profit for the FFC and SC. This can be interpreted as follows: a higher level of service and privacy protection perceived by consumers implies that consumers are willing to pay more for the products, which naturally stimulates the FFC and SC to charge higher prices to increase revenue. The smaller the negative effect of consumer privacy information leakage and consumers spending time verifying information perceived by consumers, and the smaller price sensitivity coefficient of consumers also implies that customers are willing to pay more for the products. Therefore, it is crucial for consumers to truly perceive the level of service and privacy protection provided by FFCs, and FFCs introduce blockchain platform in SLSC that can precisely meet this demand.

For FFCs, with the improvement of FFC investment in logistics information services, the services added value will increase, the corresponding cost will also increase. As a result, the FFC's profit will be affected. Only when the service level input is higher than a specific threshold, and the profit of the FFC increases with the service level. Recall that a higher γ represents that consumers will have higher trust in the logistics information service provided by the FFC. It means that the higher γ, the higher the level of service is perceived by the consumer. Therefore, it is urgent for FFCs to eliminate the negative impact caused by consumers' distrust with the help of blockchain platforms.

As the dominant player in the SLSC, SCs have higher bargaining power in the SLSC. Therefore, the profit of the SC is greater than that of the FFC. So, FFCs have a great incentive to increase their bargaining power in the SLSC to increase their profits by introducing a blockchain platform.

5.1.2. Stackelberg game of Model B

Consistent with the analysis method in Section 5.1.1, the equilibrium results of Model B are derived.

Proposition 5.3. *Through Stackelberg game analysis, the equilibrium results in Model B are:*

$$D_2^{\mathrm{S-B}*} = (\alpha + \theta + \rho - \varepsilon(c_b + \varphi(c_f + c_s)))/4, \tag{15}$$

$$P^{\mathrm{S-B}*} = (3(\alpha + \theta + \rho) + \varepsilon c_b + \varepsilon\varphi(c_f + c_s))/4\varepsilon, \tag{16}$$

$$w^{\mathrm{S-B}*} = (\alpha + \theta + \rho - \varepsilon(c_b + \varphi c_f - \varphi c_s - 2e_s))/2\varepsilon, \tag{17}$$

$$\pi_f^{\mathrm{S-B}*} = \Big((\alpha + \theta + \rho - \varepsilon(c_b + \varphi c_f + \varphi c_s))^2 - 8k\varepsilon\theta^2\Big)/16\varepsilon, \tag{18}$$

$$\pi_s^{\mathrm{S-B}*} = (\alpha + \theta + \rho - \varepsilon(c_b + \varphi c_f + \varphi c_s))^2/8\varepsilon. \tag{19}$$

5.1.3. Stackelberg game of Model J

Proposition 5.4. *Under Model J, the equilibrium results through Stackelberg game analysis are as follows:*

$$D_2^{\mathrm{S-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi c_f + \varphi c_s))/8, \tag{20}$$

$$p^{\mathrm{S-J}*} = (c_b + 7(\alpha + \theta + \rho) + c_m + \varphi c_f + \varphi c_s)/8, \tag{21}$$

$$w^{\mathrm{S-J}*} = (\alpha - c_b + \theta + \rho - c_m + 2e_s - \varphi c_f + \varphi c_s)/2, \tag{22}$$

$$x^{\mathrm{S-J}*} = (\alpha - c_b + \theta + \rho - c_m + 4e_f + 3\varphi c_f - \varphi c_s)/4, \tag{23}$$

$$\pi_m^{\mathrm{S-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi c_f + \varphi c_s))^2/64\varepsilon - k\theta^2/2, \tag{24}$$

$$\pi_f^{\mathrm{S-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi c_f + \varphi c_s))^2/32\varepsilon, \tag{25}$$

$$\pi_s^{\mathrm{S-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi c_f + \varphi c_s))^2/16\varepsilon. \tag{26}$$

Proposition 5.5. *In Model J and Model B, (i) $p^{\mathrm{S-B}*}$, $p^{\mathrm{S-J}*}$, $w^{\mathrm{S-B}*}$, $w^{\mathrm{S-J}*}$ and $x^{\mathrm{S-J}*}$ are increasing in θ, ρ; And $w^{\mathrm{S-J}*}$, $w^{\mathrm{S-B}*}$ and $x^{\mathrm{S-J}*}$ are increasing in e_i; (ii) when $\theta > \theta_2$, $\theta_2 = (\alpha + \rho - \varepsilon(c_b + \varphi(c_f + c_s)))/(8k\varepsilon - 1)$, $\pi_f^{\mathrm{S-B}*}$ is increasing in θ; $D_2^{\mathrm{S-J}*}$ and $\pi_s^{\mathrm{S-B}*}$ are increasing in θ; (iii) $\pi_f^{\mathrm{S-B}*}$, $\pi_f^{\mathrm{S-J}*}$,$\pi_s^{\mathrm{S-B}*}$ and $\pi_s^{\mathrm{S-J}*}$ are decreasing in c_b, ε, and increasing in ρ.*

Propositions 5.5 indicates that (1) a higher level of service and privacy protection as perceived by consumers implies that customers are willing to pay more for the products, which naturally stimulates the FFC and SC to charge higher prices to increase the revenue. The commission fee only affects the optimal ocean freight and handling charge fees. Specifically, the optimal ocean freight and handling charge fees are increasing in e_i. This is consistent with the fact. As the increasing of the commission fee e_i, the FFC and SC would increase w and x naturally to maximize their personal revenue. From the platform's perspective, as the ocean freight and handling charge fees increases, he would also correspondingly increase the total freight to avoid losing revenue. The FFC and SC must pay commission fee to the platform once they generate transactions on the platform. Thus, it would be more eager for the FFC and MSC to increase their prices than the platform to increase his price. (2) With the service level increase, the SC's profit would increase. However, the FFC's profit would increase only when the service level is within a certain threshold. In the two cases of Model T and Model B, the two thresholds at the service level are different, which has an impact significantly on the optimal decision. This result is consistent with the fact that, as the service level increases, the FFC would invest more costs to improve the service level, which will significantly affect the profit. However, the SC can free ride and gain more benefits as the FFC improves its service level. (3) In addition, consumers become more price-sensitivity, and blockchain costs will hurt the profits of FFCs and SCs. The protection level of consumers' personal privacy information increase is good for the profits of FFCs and SCs.

Proposition 5.6. *Compare the Model B and Model J, and the comparison results show that: (i) $D_2^{\mathrm{S-B}*} > D_2^{\mathrm{S-J}*}$, $p^{\mathrm{S-B}*} < p^{\mathrm{S-J}*}$, $w^{\mathrm{S-B}*} > w^{S-J*}$. (ii) $\pi_s^{\mathrm{S-B}*} > \pi_s^{\mathrm{S-J}*}$, $\pi_f^{\mathrm{S-B}*} > \pi_m^{\mathrm{S-J}*}$. (iii) $\pi_s^{\mathrm{S-B}*} > \pi_f^{\mathrm{S-B}*}$ and $\pi_s^{\mathrm{S-B}*}/\pi_f^{\mathrm{S-B}*} < 2$; $\pi_s^{\mathrm{S-J}*} > \pi_f^{\mathrm{S-J}*}$ and $\pi_s^{\mathrm{S-J}*}/\pi_f^{\mathrm{S-J}*} = 2$.*

Proposition 5.6 indicates that the optimal demand, optimal total freight, optimal ocean freight, and optimal profit in the two models are different: although optimal ocean freight in Model B is higher than that in Model J, the total freight in Model B is lower than that in Model J, and optimal demand and the platform profit in Model B (*i.e.*, the FFC) is greater than that in Model J. This is because Model B is a direct sales channel, which reduces supply chain links and enables all members of the SLSC to obtain greater profits. In Model B, the profit gap between the SC and the FFC is smaller than that in Model J, which indicates that Model B improves the bargaining power of the FFC in the SLSC.

5.2. Nash game

According to the characteristics of the decentralized and distributed structure of blockchain, there is no absolute centralized logistics enterprise in the blockchain network formed by the blockchain platform [22]. The application of blockchain technology might change the power structure of the current SLSC and make the power structure symmetrical of the members in the SLSC. For example, FFCs can obtain more logistics resources through the introduction of a blockchain platform, leading to the continuous increase of their bargaining power. The Nash game applies to situations where the members are roughly equal in strength, and neither side will make a decision based on the other's decision. This section will therefore use the Nash game to analyze the situation where blockchain platforms (*i.e.*, FFC), and SCs have equal power in the SLSC. Consequently, they make their decisions simultaneously, that is, the SC determines the w, whereas the FFC determines the p to maximize their profits, respectively. In this Nash game, a unique Nash equilibrium outcome is obtained, as shown in Propositions 5.7 and 5.8. A superscript "N" is added to denote the corresponding notation in Nash game.

5.2.1. Nash game of Model B

Proposition 5.7. *In the Nash game, the equilibrium decisions of the SC and the FFC are as follows:*

$$D_2^{\mathrm{N-B}*} = (\alpha - c_b\varepsilon + \rho + \theta - \varepsilon(\varphi c_f + \varphi c_s))/3, \tag{27}$$
$$p^{\mathrm{N-B}*} = (2\alpha + c_b\varepsilon + 2(\theta + \rho) + \varepsilon\varphi(c_f + c_s))/3\varepsilon, \tag{28}$$
$$w^{\mathrm{N-B}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon\varphi c_f + 3\varepsilon e_s + 2\varepsilon\varphi c_s)/3\varepsilon, \tag{29}$$
$$\pi_s^{\mathrm{N-B}*} = (\alpha - c_b\varepsilon + \rho + \theta - \varepsilon\varphi(c_f + c_s))^2/9\varepsilon, \tag{30}$$
$$\pi_f^{\mathrm{N-B}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon\varphi(c_f + c_s))^2/9\varepsilon - k\theta^2/2. \tag{31}$$

5.2.2. Nash game of Model J

Proposition 5.8. *In the Nash game, the equilibrium decisions of the members are as follows:*

$$D_2^{\mathrm{N-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi(c_f + c_s)))/4, \tag{32}$$
$$p^{\mathrm{N-J}} = (3\alpha + c_b\varepsilon + 3(\theta + \rho) + \varepsilon(c_m + \varphi c_f + \varphi c_s))/4\varepsilon, \tag{33}$$
$$w^{\mathrm{N-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m - 4e_s + \varphi c_f - 3\varphi c_s))/4\varepsilon, \tag{34}$$
$$x^{\mathrm{N-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m - 4e_f - 3\varphi c_f + \varphi c_s))/4\varepsilon, \tag{35}$$
$$\pi_s^{\mathrm{N-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi c_f + \varphi c_s))^2/16\varepsilon, \tag{36}$$
$$\pi_f^{\mathrm{N-J}*} = (\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi c_f + \varphi c_s))^2/16\varepsilon, \tag{37}$$
$$\pi_m^{\mathrm{N-J}*} = \left((\alpha - c_b\varepsilon + \theta + \rho - \varepsilon(c_m + \varphi c_f + \varphi c_s))^2 - 8k\varepsilon\theta^2\right)/16\varepsilon. \tag{38}$$

Proposition 5.9. *Compare Model B and Model J, and the comparison results show that: (i)* $D_2^{\mathrm{N-B}*} > D_2^{\mathrm{N-J}*}$, $p^{\mathrm{N-B}*} < p^{\mathrm{N-J}*}$ *and* $w^{\mathrm{N-B}*} > w^{\mathrm{N-J}*}$*; (ii)* $\pi_s^{\mathrm{N-B}*} > \pi_s^{\mathrm{N-J}*}$ *and* $\pi_f^{\mathrm{N-B}*} > \pi_m^{\mathrm{N-J}*}$*; (iii)* $\pi_s^{\mathrm{N-B}*} > \pi_f^{\mathrm{N-B}*}$ *and* $\pi_s^{\mathrm{N-J}*} = \pi_f^{\mathrm{N-J}*}$.

Table 3. Parameters.

Parameters	k	c_f	c_b	φ	θ	γ	β	α
Values	0.8	2	1	0.9	0.8	0.8	0.6	$[1, 100]$
Parameters	ρ	c_s	ε	t	c_m	λ	c_g	
Values	0.6	3	0.9	0.8	1.8	0.5	0.3	

Proposition 5.9 indicates that the optimal demand, optimal total freight, optimal ocean freight, and optimal profit in the two models are different: although optimal ocean freight in Model B is higher than that in Model J, the total freight in Model B is lower than that in Model J, and the optimal profit, optimal demand in Model B is greater than that in Model J. This is consistent with the result of Proposition 5.6. In Model B, the profit gap between the SC and the FFC is services costs $k\theta^2/2$, this implies that the FFC may have a fair concern because the SC has the behavior of free ride and can enjoy the benefits brought by the service cost paid by the FFC without paying. In Model J, the profits of SCs and FFCs are equal because SCs and FFCs play the same role in the SLSC and the power structure is symmetrical.

5.3. The value of blockchain platform

This section will discuss the potential value of blockchain platforms applied to SLSC based on equilibrium results. Following Choi [9], this paper uses the relative gaps by comparing Model T, Model B, and Model J to define the values of blockchain platforms for the FFC, SC and third-party blockchain platforms, respectively. Clearly, larger values of $\Delta\pi_f$, $\Delta\pi_s$ and $\Delta\pi_m$ imply greater values of blockchain platforms:

$$\Delta\pi_f^{\mathrm{S-B}*} = \pi_f^{\mathrm{S-B}*} - \pi_f^{\mathrm{S-T}*},\ \Delta\pi_f^{\mathrm{N-B}*} = \pi_f^{\mathrm{N-B}*} - \pi_f^{\mathrm{S-T}*},\ \Delta\pi_f^{\mathrm{S-J}*} = \pi_f^{\mathrm{S-J}*} - \pi_f^{S-T*},$$
$$\Delta\pi_f^{\mathrm{N-J}*} = \pi_f^{\mathrm{N-J}*} - \pi_f^{S-T*};$$
$$\Delta\pi_s^{\mathrm{S-B}*} = \pi_s^{\mathrm{S-B}*} - \pi_s^{\mathrm{S-T}*},\ \Delta\pi_s^{\mathrm{N-B}*} = \pi_s^{\mathrm{N-B}*} - \pi_s^{\mathrm{S-T}*},\ \Delta\pi_s^{\mathrm{S-J}*} = \pi_s^{\mathrm{S-J}*} - \pi_s^{\mathrm{S-T}*},$$
$$\Delta\pi_s^{\mathrm{N-J}*} = \pi_s^{\mathrm{N-J}*} - \pi_s^{\mathrm{S-T}*};$$
$$\Delta\pi_m^{\mathrm{S-J}*} = \pi_m^{\mathrm{S-J}*} - \pi_f^{\mathrm{S-T}*},\ \Delta\pi_m^{\mathrm{N-J}*} = \pi_m^{\mathrm{N-J}*} - \pi_f^{\mathrm{S-T}*};$$

Then, to numerically examine the value of blockchain platforms by comparing the three models of profits in the different channel structures and different game situations, respectively. According to the problem description and the relevant paper Zarouri *et al.* [43] and Zhong *et al.* [8], it is assumed that the basic parameter values in numerical experiments are shown in Table 3.

Figure 8 shows the value of blockchain platform for the FFC. As shown in Figure 8, in the Stackelberg game scenario, the value of the blockchain platform in Model B for the FFC is significant, and the profit of the FFC with the increase of the market demand base α. Also, it finds that the value of the blockchain platform in Model J is not significant, and the FFC's profit decreases. That is, it is better for the FFC to refuse to adopt Model J, and the FFC is more likely to maintain Model T in this scenario. In the Nash game scenario, compared with Model J, the value of blockchain platform in Model B is more significant, and the profit of FFC with the increase of the market demand base α. Comparing the two scenarios of the Stackelberg game and the Nash game, it can find that the value of the blockchain platform in Model B is maximum and can make the FFC's profit maximum in the Nash game scenario. In a comprehensive view, although FFC adopts the Model B to pay huge blockchain costs, the value of blockchain platforms is significant for FFCs. Especially when the power structure is symmetric, for FFCs, the optimal strategic decision is to adopt Model B, which maximizes the value of the blockchain platform.

Figure 9 shows the value of blockchain platform for SC. In the Stackelberg game scenario, the value of the blockchain platform in Model B for SC is significant, and the profit of the SC with the increase of the market

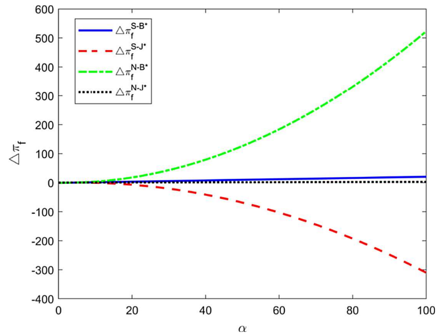

FIGURE 8. The value of blockchain platform for FFC.

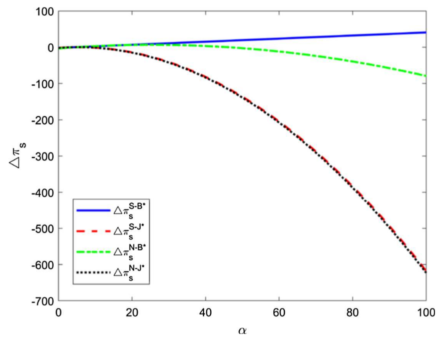

FIGURE 9. The value of blockchain platform for SC.

demand base α. While Model J make the SC's profit decrease with the increase of the market demand base α, that is, it is better for the SC to refuse Model J. In the Nash game scenario, the value of the blockchain platform in Model B and Model J for SC is not significant, and the profit of the SC decreases with the increase of the market demand base α. So, in this scenario, the SC most likely to maintain the Model T. That is because when the blockchain platform changes the power structure, the SC's bargaining power reduces in the SLSC, and the profit also reduces, which is consistent with the fact situation. By comparing the two game scenarios, it can find that the value of blockchain platforms is only significant in Model B for SCs when the power structure is asymmetry.

Figure 10 shows the value of blockchain platforms for a third-party blockchain platform. From the perspective of the platform, the value of the blockchain platform in Model J is not significant in the Stackelberg game scenario. However, the value of blockchain platform in Model J is significant in the Nash game scenario, and the profit of platform with the increase of the market demand base α. This implies that third-party blockchain platforms are profitable in the Nash game scenario because the platform has bargaining power in that scenario.

Clearly, comparing Figures 8–10, it can know that the value of the blockchain platform in Model B for FFC is significant, especially in the Nash game scenario. However, in the Stackelberg game scenario, Model B can make both the FFC and the SC gain and achieve a win–win situation. This shows that if the FFC introduces the blockchain platform, it will attract more upstream members if it does not change the current power structure and does not pose a threat to the incumbents. However, from the perspective of FFCs, they can gain more profits if they can continuously improve their bargaining power in the SLSC by introducing a blockchain platform.

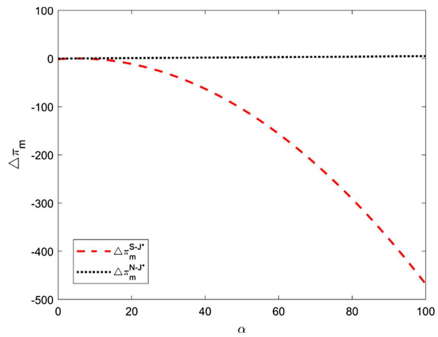

FIGURE 10. The value of blockchain platform for the third-party blockchain platform.

6. Sensitivity analysis

In this section, to illustrate the influence of perceived utility of consumers on various equilibrium strategies, the following comparative analysis is made through numerical examples. Refer to Yan *et al.* [44], the sensitivity of the objective functions regarding some parameters (θ, ρ, ε, c_b) is investigated. It should be noted that due to the complexity of the problem, the above parameters are only considered in a small scope. The results are represented below.

(1) The sensitivity analysis of the objective functions concerning θ, ρ is conducted within $[0.1, 1]$ in three channel models in both the Stackelberg and Nash games scenarios. The obtained results in Figures 11–15 demonstrate that all optimal total freight, optimal demand and ocean freight in both the Stackelberg and Nash games increase as θ, ρ increases. This result implies that consumers are more willing to pay a higher price for services as the level of service and privacy protection increases. Figure 11 declares that optimal total freight in Model J of the Stackelberg game scenario is highest, in Model B of the Nash game scenario is lowest. This result implies that in Model B of the Nash game, consumers can obtain logistics services through lower total freight, which brings greater welfare to consumers. Figure 12 declares that optimal ocean freight is highest in Model T of the Stackelberg games, in Model J of the Nash game scenario is lowest. This is because, in Model T, the SC is in a dominant position and has greater bargaining power. Figure 13 declares that optimal demand is highest in Model B of the Nash games, in Model J of the Stackelberg game scenario is lowest. This result implies that Model B of the Nash game can attract more consumers.
The obtained results in Figures 14 and 15 demonstrate that all optimal profits of FFC and SC increase as θ, ρ increases. This result implies that consumers are more willing to pay a higher price for services as the level of service and privacy protection increases. Figure 14 declares that the optimal profit of FFC in Model B of the Nash game scenario is highest, in Model J of the Stackelberg game scenario is lowest. This implies that for the FFC, although it takes a huge cost to build the blockchain platform, the FFC's bargaining power in the SLSC can be improved by the blockchain platform. Then, in this case, compared with Model T and Model J, Model B is the best choice for the FFC. The obtained results in Figure 15 demonstrate that the optimal profit of SC in Model B of the Stackelberg game scenario is highest, in Model J of the Nash game scenario is lowest. This shows that SCs can only make profits when they maintain their dominant position, which is consistent with the real economic environment. This is the implication that for SCs, if the application of the blockchain platform does not change the current power structure, it can support the blockchain platform.

(2) The sensitivity analysis of the objective functions regarding c_b, ε is considered within $[0.1, 2]$ and $[0.1, 1]$. The obtained results in Figure 16 demonstrate that the impact of c_b, ε on all optimal total freight in both the Stackelberg and Nash games is not monotonic as θ, ρ increases. When the price sensitivity coefficient

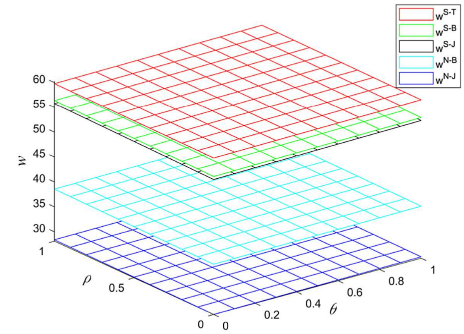

FIGURE 11. Impact of θ, ρ on the total freight of the Nash and Stackelberg game.

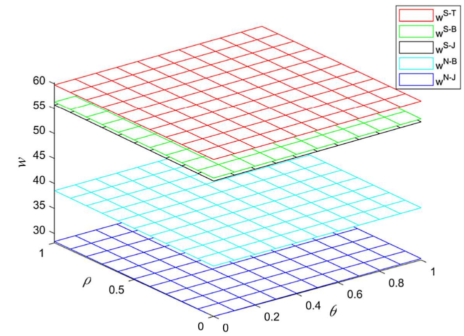

FIGURE 12. Impact of θ, ρ on the ocean freight of the Nash and Stackelberg game.

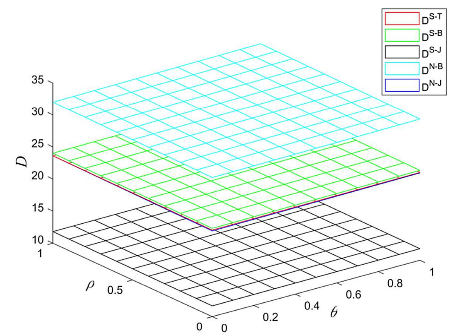

FIGURE 13. Impact of θ, ρ on the demand of the Nash and Stackelberg game.

of consumers is low, optimal total freight is always in a high state regardless of the blockchain cost. The optimal total freight decreases with the increase of consumer sensitivity coefficient. This implies that the price sensitivity coefficient of consumers has a greater impact on the total freight than the blockchain cost. Figure 16 declares that optimal total freight in Model J of the Stackelberg game scenario is highest, in Model B of the Nash game scenario is lowest. Figure 17 declares that optimal demand is highest in Model B of the Nash games, in Model J of the Stackelberg game scenario is lowest. This result implies that Model B of the Nash game can attract more consumers. The obtained results in Figures 18–20 demonstrate that

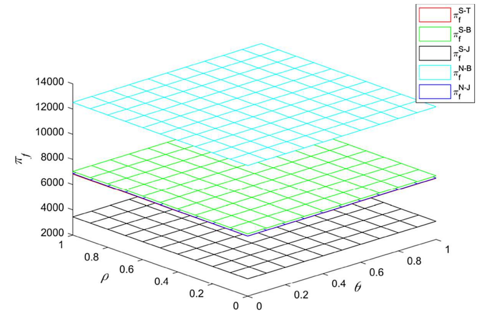

FIGURE 14. Impact of θ, ρ on the FFC's profit of the Nash and Stackelberg game.

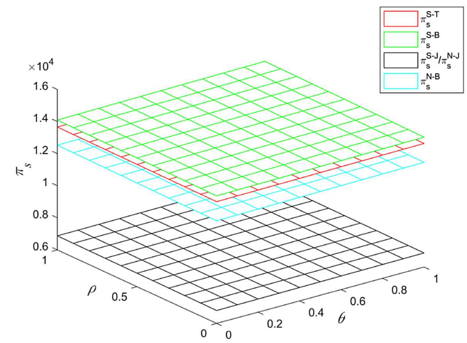

FIGURE 15. Impact of θ, ρ on the SC's profit of the Nash and Stackelberg game.

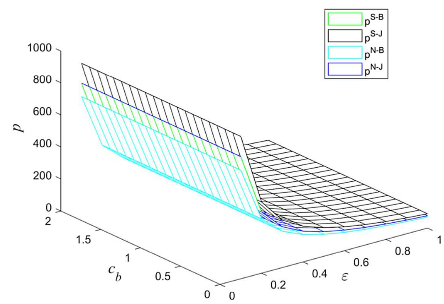

FIGURE 16. Impact of c_b, ε on the total freight of the Nash and Stackelberg game.

the impact of c_b, ε on all profit of supply chain members in both the Stackelberg and Nash games is not monotonic. When the price sensitivity coefficient of consumers is low, profit of FFC, SC and platform is always in a high state regardless of the blockchain cost c_b. It shows that the equilibrium profit of the supply chain members is negatively related to the price sensitivity coefficient of consumers. It is seen from the slopes of the curves depicted in Figures 18–20 that the profit of the supply chain members is influenced more by the price sensitivity coefficient of consumers ε than blockchain cost c_b. From the slopes of the curves depicted in Figures 18–20, it can be seen that the lower the price sensitivity of consumers, the more beneficial the profit of supply chain members. Therefore, supply chain members will pay more attention to the price sensitivity coefficient ε of consumers and reduce its negative impact. Figure 18 declares that the

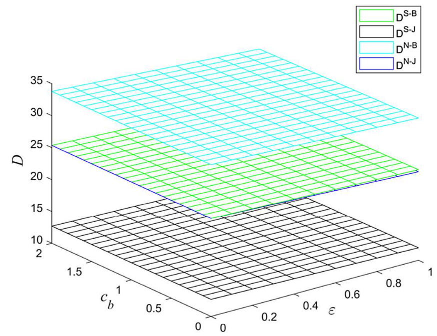

FIGURE 17. Impact of c_b, ε on the demand of the Nash and Stackelberg game.

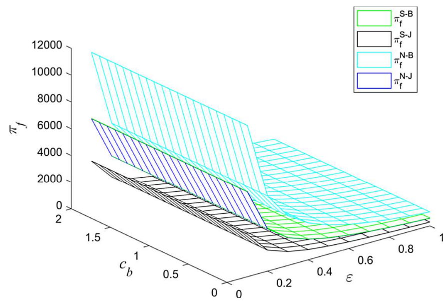

FIGURE 18. Impact of c_b, ε on the FFC's profit of the Nash and Stackelberg game.

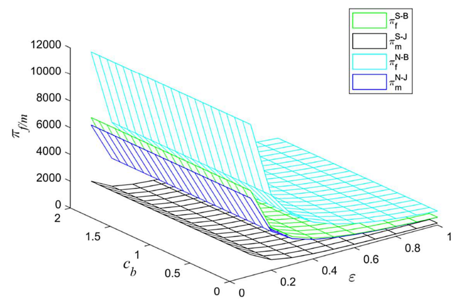

FIGURE 19. Impact of c_b, ε on the platform's profit of the Nash and Stackelberg game.

optimal profit of FFC in Model B of the Nash games scenario is highest, in Model J of the Stackelberg game scenario is lowest. Figure 19 demonstrates that the optimal profit of platform in Model B of the Nash games scenario is highest, in Model J of the Stackelberg game scenario is lowest. Figure 20 also demonstrates that the optimal profit of SC in Model B of the Stackelberg games scenario is highest, in Model J of the Nash game scenario is lowest.

The experiments' outcomes are represented in Table 4. The analytical results are obtained as follows:

(1) From the perspective of consumers, when the power structure of the supply chain is symmetric, consumers in Model B can get better service by providing lower total freight and obtaining the maximum welfare. Because

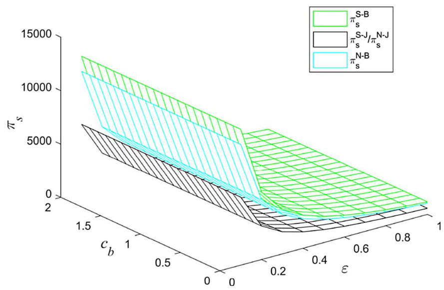

FIGURE 20. Impact of c_b, ε on the SC's profit of the Nash and Stackelberg game.

TABLE 4. Chain members' obtained profits of the experiments in the Stackelberg and Nash game.

		Stackelberg game									Nash game					
		Model T			Model B			Model J			Model B			Model J		
ρ	θ	p^{S-T}	π_f^{S-T}	π_s^{S-T}	p^{S-B}	π_f^{S-B}	π_s^{S-B}	p^{S-J}	π_f^{S-J}	π_s^{S-J}	p^{N-B}	π_f^{N-B}	π_s^{N-B}	p^{N-J}	π_f^{N-J}	π_s^{N-J}
0.25	0.25	84.1	617.3	1235.2	85.1	633.8	1268	98.6	309.3	618.6	76.28	1126.9	1127.1	85.5	618.6	618.6
0.5	0.5	84.4	621.6	1243.7	85.5	640.4	1281.3	99	312.6	625.1	76.7	1138.7	1138.9	85.9	625.1	625.1
0.75	0.75	84.7	625.8	1252.2	85.9	647.1	1294.7	99.5	315.9	631.8	77	1150.6	1150.8	86.3	631.7	631.7
1	1	85	630.1	1260.9	86.3	653.8	1308.1	100	319.2	638.4	77.4	1162.6	1162.8	85.7	638.4	638.4

		Stackelberg game							Nash game						
		Model B			Model J				Model B			Model J			
ε	c_b	p^{S-B}	π_f^{S-B}	π_s^{S-B}	p^{S-J}	π_f^{S-J}	π_s^{S-J}	π_m^{S-J}	p^{N-B}	π_f^{N-B}	π_s^{N-B}	p^{N-J}	π_f^{N-J}	π_s^{N-J}	π_m^{N-J}
0.25	0.25	305.4	2510.4	5021.3	355.7	1247.2	2494.4	623.3	272	4463.1	4463.4	305.7	2494.4	2494.4	2319.2
0.5	0.5	153.4	1222.4	1222.4	178.2	603.3	1206.6	301.4	136.9	2173.3	2173.6	153.7	1206.6	1206.6	1155.1
0.75	0.75	102.7	791.3	791.3	119.1	387.9	775.8	193.7	91.9	1407	1407.3	103	775.8	775.8	765
1	1	77.4	574.5	574.5	89.6	279.7	559.3	139.6	69.4	1021.6	1021.9	77.8	559.3	559.3	568.5

Model B of the Nash game scenario is the best scenario for consumers, and Model J of the Stackelberg game scenario is the worst scenario for consumers.

(2) From the perspective of FFCs, whether the power structure is symmetrical or asymmetrical, Model B can give more profits to FFCs. It exactly explains why many FFCs applying blockchain platforms choose a self-built platform channel in the market. For instance, CJ Logistics[4] has partnered with AWS to invest in a "blockchain pharmaceutical logistics system". Moreover, the FFC can obtain greater when the power structure is symmetrically rather than asymmetrical. Because Model B of the Nash game scenario is the best scenario for FFCs, and Model J of the Stackelberg game scenario is the worst scenario for FFCs. For example, it can be seen from Table 4 that when $c_b = 0.25$ and the power structure is asymmetrical, the profit of FFC in Model B is \$2510.4; when the power structure asymmetrical, the profit of FFC in Model B is \$4463.1, profit increased by approximately 78%. From the perspective of SCs, only Model B with the power structure asymmetric can benefit. Because only Model B of the Stackelberg game scenario is the best scenario for the SC, other scenarios do not benefit the SC. It also explains from the side one of the reasons why the application of blockchain technology in the shipping logistics industry is not smooth. In the real shipping logistics market, although it can be observed that blockchain has been widely implemented in the SLSC, some companies refuse to adopt blockchain. This phenomenon can be explained by the fact that the application of blockchain platform does not necessarily bring substantial benefits to each member of the supply chain. For example, Maersk, which has a market capitalization of US\$37.46 billion and is ranked

[4]https://www.cjlogistics.com.

455th on the list of the world's most valuable companies, is unwilling to continue funding the continuation of the promising blockchain logistics platform TradeLens. It is because Maersk, as an SC, can make itself profitable in the traditional shipping logistics supply chain, especially in the existing market power structure with asymmetric where Maersk has an absolute advantage in the SLSC.

(3) We compare the Stackelberg and Nash games scenarios. Interestingly, we find that in the Stackelberg game scenario, that is, the power structure is asymmetric, Model B can make the FFC and the SC achieve a win–win situation. However, this is not the best situation for FFCs and consumers. When the power structure is symmetric, Model B can make the FFC and the consumers achieve a win–win situation. Therefore, it is necessary to design contract coordination so that the FFCs, SCs, and consumers can achieve a win–win–win. It is not difficult to understand in practice. The smooth application of blockchain platforms in the SLSC requires the cooperation of shipping logistics enterprises under the appropriate coordination contract to fully mobilize the resources of all parties, cooperate to give full play to their advantages, and maximize the overall benefits. For example, Kuehne + Nagel has allied with Accenture, ABInbev, APL, and a customs organization to test a blockchain solution for the supply chain successfully. GSBN, a blockchain international trade platform created by OOCL in conjunction with eight other leading global SCs and port companies, has successfully collaborated on a pilot Cargo Release application, providing consumers with a digital, transparent, efficient, and paperless logistics solution.

7. Conclusion

7.1. Concluding remarks

Blockchain is widely used in shipping logistics information tracing in SLSC due to no information tampering. Consumers can improve their experience when using blockchain platforms to send goods. Motivated by the real-world practice of using blockchain to trace the information in SLSC, this paper explores the value of the blockchain platform when FFC introduces it in different channels in SLSC. Moreover, as differ from prior literature on the value of the blockchain, *e.g.*, Liu *et al.* [15], Yu *et al.* [12] and Choi [9], this paper analyzes the value of the blockchain platform when FFCs in the SLSC introduce the blockchain platform in different channel structures considering the perceived utility of consumers. Moreover, this paper also analyzes the proposed model in game-theoretical resulting from different power structures in the channel (*i.e.*, Stackelberg and Nash). Specifically, this paper develops three channel models (1) Model T (*i.e.*, traditional logistics supply chain channel), (2) Model B (*i.e.*, FFCs applied a blockchain platform *via* a self-built platform channel), (3) Model J (*i.e.*, FFCs applied a blockchain platform *via* joining a third-party platform channel), to discuss which channels are optimal for FFCs to apply blockchain platforms to benefit the SLSC and drive the conditions under which the supply chain achieves the win–win outcome.

Several interesting conclusions are drawn through the above analysis: there is a counter-intuitive result that blockchain adoption does not necessarily benefit consumers. For consumers, although blockchain implementation in the SLSC increases consumer confidence in logistics information service, and make consumers purchase service at a lower price in some situations (*e.g.*, Model B of the Nash game scenario), consumers may still face declining consumer surplus (*e.g.*, Model J of the Stackelberg and Nash game scenario). Meanwhile, consumer perception of the level of service and privacy protection and consumer sensitivity to price plays an important role in influencing the value of blockchain platforms. Specifically, FFC and SC profits in the three-channel models can increase when consumer perception of the level of service and privacy protection is high and consumer sensitivity to price is low. The FFC adopting the blockchain platform can bring more value if it can provide consumers with a good logistics information service level, protect consumers' private information and create a trustworthy environment.

In addition, another counter-intuitive result is that the value of blockchain platforms is not always significant. The best channel structure for FFCs to introduce blockchain platforms to maximize the value of the blockchain platform mainly includes: regardless of whether the power structure is symmetrical or asymmetrical, FFC adopts Model B instead of Model J, in which the blockchain platform can help FFC increase profits, and the value of blockchain is significant. Moreover, the FFC can obtain greater when power structure is symmetrically rather than that asymmetrical. However, the value of blockchain platforms for SC is not necessarily significant. The value of the blockchain platform for SC is significant only in Model B with the power structure asymmetric. Therefore, the value of the blockchain platform in Model B with the power structure asymmetrical for both FFCs and SCs is significant, achieving a win–win situation.

7.2. Managerial insights

Some meaningful managerial insights are drawn, which can be used for reference by relevant managers. First, for FFC. (1) FFCs aim at improving consumer service and experience by adopting blockchain platforms and should pay attention to channel choice and how it influences the FFC's profitability. (2) FFCs can actively invest in building a self-built platform to introduce blockchain platforms in SLSC. Although FFCs have to pay huge the blockchain cost for a self-built platform, they can benefit. This conclusion also explains why many FFCs are actively investing in building blockchain platforms to upgrade their logistics systems at the expense of huge blockchain costs. For instance, Smart freight forwarder CargoX has launched and uses its blockchain platform CargoX for the shipping industry, which serves approximately 87 000 companies worldwide. CargoX aims to trigger digital transformation in the supply chain and provide clean workflows and a refined consumer experience[5]. (3) FFCs should actively apply blockchain platform to change the power structure in the SLSC and enhance their bargaining power to obtain greater profits. Because when the application of a blockchain platform changes the current power structure so that the power structure between members in the SLSC is symmetrical, FFCs can gain the most benefit in the case of investing in building a blockchain platform. (4) When the FFC builds the blockchain platform, it is necessary to consider its internal blockchain cost and the benefits of other members of the SLSC. That may indeed generate significant impacts on the blockchain platform's profitability. Our findings show that only in the case in which the power structure is asymmetric and the FFC's self-built platform achieves a win–win outcome for FFC and SC. Thus, when the FFC induces the other members of the SLSC, such as the SC, to join FFC's self-built platform for cooperation, the FFC can offer the SC more generous contracts, such as reduced commission rates and provide logistic service support.

Second, for SCs. If the blockchain platform does not change the current power structure, the value of the blockchain platform for SC is significant in Model B. Therefore, in this case, SCs can actively join the application of blockchain platform, even if they have to pay commission to the platform. But that does not mean SCs' ultimate market share will expand. SCs should always be aware that FFCs will continuously improve their bargaining power and increase their market share in the SLSC through the blockchain platform. In summary, SCs must balance benefits and costs, avoid confusing superficial benefits, and always remain competitiveness.

7.3. Future studies

Afterward, some limitations and further research directions are further presented. First, there are only two logistics supply chain members (*i.e.*, FFC and SC) in the context of this paper. In reality, the blockchain platform also contains other logistics supply chain members such as storage companies, tow companies, etc., which can be considered in future research. Second, the application of blockchain platform in SLSC is complex, and the analysis about it should be more complex and interesting. Therefore, future research will extend the application of blockchain technology to the multi-stage supply chain model. For example, discuss how supply chain members join to the blockchain platform at different stages affects the operation of the SLSC.

Appendix A. All proofs

Proof of Proposition 5.1. We use the backward induction to solve the problem. The FFC's and the SC's profits in Model T are: $\pi_f^{\mathrm{T}}(p) = (p - w - c_f - c_g)D_1 - k\theta^2/2$, $\pi_s^{\mathrm{T}}(w) = (w - c_s - c_g)D_1$. As $\frac{\mathrm{d}^2\pi_f^{\mathrm{T}}(p)}{\mathrm{d}p^2} < 0$, we can derive π_f^{T} is concave. So, in Stackelberg game of Model T, when the w^{S-T} is given, the optimal total

[5] https://cargox.io/.

freight is: $p^{\mathrm{S-T}*}|w = (\alpha - \beta t + w\varepsilon + \theta\gamma + \lambda(\rho-1) + \varepsilon(c_f + c_g))/2\varepsilon$. Put $p^{\mathrm{S-T}*}|w = (\alpha - \beta t + w\varepsilon + \theta\gamma + \lambda(\rho-1) + \varepsilon(c_f + c_g))/2\varepsilon$ into $\pi_s^{\mathrm{T}}(w) = (w - c_s - c_g)D_1$. So, we can rewrite the SC' profits function as follows: $\pi_s^{\mathrm{T}}(w) = (\alpha - \beta t - w\varepsilon + \theta\gamma - \lambda(1-\rho) - \varepsilon(c_f + c_s))(w - c_g - c_s)/2$. Since $\frac{\mathrm{d}^2\pi_s^{\mathrm{T}}(w)}{\mathrm{d}w^2} < 0$, we know that π_s^{T} is concave in w and optimizing it yields the optimal ocean freight in Stackelberg game of Model T $w^{\mathrm{S-T}*} = \frac{\alpha-\beta t+\theta\gamma+\lambda(\rho-1)-\varepsilon c_f+\varepsilon c_s}{2\varepsilon}$. Then, with $w^{S-T*} = \frac{\alpha-\beta t+\theta\gamma+\lambda(\rho-1)-\varepsilon c_f+\varepsilon c_s}{2\varepsilon}$, we can easily find the optimal total freight: $p^{\mathrm{S-T}*} = \frac{3(\alpha-\beta t+\theta\gamma+\lambda(\rho-1)+\varepsilon(c_f+2c_g+c_s))}{4\varepsilon}$. With $p^{\mathrm{S-T}*}$ and w^{S-T*}, we can get the optimal demand: $D_1^{\mathrm{S-T}*} = \frac{\alpha-\beta t+\theta\gamma+\lambda(\rho-1)-\varepsilon(c_f+2c_g+c_s)}{4}$. Thus, we can get the optimal profits of the FFC and SC can be derived as: $\pi_f^{\mathrm{S-T}*} = \frac{(\alpha-\beta t+\theta\gamma+\lambda(\rho-1)-\varepsilon(c_f+2c_g+c_s))^2-8k\varepsilon\theta^2}{16\varepsilon}$, $\pi_s^{\mathrm{S-T}*} = \frac{(\alpha-\beta t+\theta\gamma+\lambda(\rho-1)-\varepsilon(c_f+2c_g+c_s))^2}{8\varepsilon}$. □

Proof of Proposition 5.2. For the operations with the Model T: (i) from Proposition 5.1, we can get that $\frac{\partial p^{\mathrm{S-T}*}}{\partial\theta} = \frac{3\lambda}{4\varepsilon} > 0$, $\frac{\partial p^{\mathrm{S-T}*}}{\partial\lambda} = \frac{3\theta}{4\varepsilon} > 0$, $\frac{\partial p^{\mathrm{S-T}*}}{\partial\rho} = \frac{3\lambda}{4\varepsilon} > 0$; $\frac{\partial w^{\mathrm{S-T}*}}{\partial\theta} = \frac{\gamma}{2\varepsilon} > 0$, $\frac{\partial w^{\mathrm{S-T}*}}{\partial\gamma} = \frac{\theta}{2\varepsilon} > 0$, and $\frac{\partial w^{\mathrm{S-T}*}}{\partial\rho} = \frac{\lambda}{2\varepsilon} > 0$. Similarly, we can get $\frac{\partial\pi_s^{\mathrm{S-T}*}}{\partial\theta} > 0$, $\frac{\partial\pi_s^{\mathrm{S-T}*}}{\partial\gamma} > 0$, $\frac{\partial\pi_s^{\mathrm{S-T}*}}{\partial\rho} > 0$, $\frac{\partial D_1^{\mathrm{S-T}*}}{\partial\gamma} > 0$, $\frac{\partial D_1^{\mathrm{S-T}*}}{\partial\theta} > 0$, and $\frac{\partial D_1^{\mathrm{S-T}*}}{\partial\rho} > 0$. (ii) From Proposition 5.1, we can get that $\frac{\partial p^{\mathrm{S-T}*}}{\partial\varepsilon} = -\frac{3(\alpha-\beta t+\gamma\theta+\lambda(\rho-1))}{4\varepsilon^2} < 0$, $\frac{\partial p^{\mathrm{S-T}*}}{\partial\beta} = -\frac{3t}{4\varepsilon} < 0$, $\frac{\partial p^{\mathrm{S-T}*}}{\partial\lambda} = \frac{3(\rho-1)}{4\varepsilon} < 0$; $\frac{\partial w^{\mathrm{S-T}*}}{\partial\beta} = -\frac{t}{2\varepsilon} < 0$, $\frac{\partial w^{\mathrm{S-T}*}}{\partial\lambda} = \frac{\rho-1}{2\varepsilon} < 0$ and $\frac{\partial w^{\mathrm{S-T}*}}{\partial\varepsilon} = -\frac{\alpha-t\beta+\gamma\theta+\lambda(\rho-1)}{2\varepsilon^2} < 0$. Similarly, we can get $\frac{\partial D_1^{\mathrm{S-T}*}}{\partial\beta} < 0$, $\frac{\partial D_1^{\mathrm{S-T}*}}{\partial\lambda} < 0$, $\frac{\partial D_1^{\mathrm{S-T}*}}{\partial\varepsilon} < 0$, $\frac{\partial\pi_s^{\mathrm{S-T}*}}{\partial\beta} < 0$, $\frac{\partial\pi_s^{\mathrm{S-T}*}}{\partial\lambda} < 0$ and $\frac{\partial\pi_s^{\mathrm{S-T}*}}{\partial\varepsilon} < 0$. (iii) From Proposition 5.1, we can get that $\frac{\partial\pi_f^{\mathrm{S-T}*}}{\partial\theta} = \frac{\gamma(\alpha-\beta t+\gamma\theta+\lambda(\rho-1)-\varepsilon(c_f+2c_g+c_s))}{8\varepsilon} - k\theta$. Let $\theta_1 = \frac{\gamma(\alpha-\beta t-\lambda+\lambda\rho-\varepsilon(c_f+2c_g+c_s))}{8k\varepsilon-\gamma^2}$, so, when $\theta > \theta_1$, $\frac{\partial\pi_f^{\mathrm{S-T}*}}{\partial\theta} > 0$. Similarly, we can get $\frac{\partial\pi_f^{\mathrm{S-T}*}}{\partial\gamma} > 0$, $\frac{\partial\pi_f^{\mathrm{S-T}*}}{\partial\rho} > 0$, $\frac{\partial\pi_f^{\mathrm{S-T}*}}{\partial\beta} < 0$, $\frac{\partial\pi_f^{\mathrm{S-T}*}}{\partial\lambda} < 0$ and $\frac{\partial\pi_f^{\mathrm{S-T}*}}{\partial\varepsilon} < 0$. (iv) From Proposition 5.1, we can get that $\pi_s^{\mathrm{S-T}*} - \pi_f^{\mathrm{S-T}*} = \frac{8k\varepsilon\theta^2+(\alpha-\beta t+\theta\gamma+\lambda(\rho-1)-\varepsilon(c_f+2c_g+c_s))^2}{16\varepsilon}$, as $D_1^{\mathrm{S-T}*} = \frac{(\alpha-\beta t+\theta\gamma+\lambda(\rho-1)-\varepsilon(c_f+2c_g+c_s))}{4} > 0$, we can get $(\alpha - \beta t + \theta\gamma + \lambda(\rho-1) - \varepsilon(c_f + 2c_g + c_s)) > 0$, so $\pi_s^{\mathrm{S-T}*} - \pi_f^{\mathrm{S-T}*} > 0$. □

Proof of Proposition 5.3. Similar to the Proof of Proposition 5.1 (Q.E.D.) □

Proof of Proposition 5.4. Similar to the Proof of Proposition 5.1 (Q.E.D.) □

Proof of Proposition 5.5. In Model J and Model B, we can get that (i) From Propositions 5.3 to 5.4, we can get that $\frac{\partial p^{\mathrm{S-B}*}}{\partial\theta} = \frac{3}{4\varepsilon} > 0$, $\frac{\partial p^{\mathrm{S-B}*}}{\partial\rho} = \frac{3}{4\varepsilon} > 0$, $\frac{\partial w^{\mathrm{S-B}*}}{\partial\rho} = \frac{1}{2\varepsilon} > 0$, $\frac{\partial w^{\mathrm{S-B}*}}{\partial\theta} = \frac{1}{2\varepsilon} > 0$ and $\frac{\partial w^{\mathrm{S-B}*}}{\partial e_s} = 1 > 0$. Similarly, we can get that $\frac{\partial p^{\mathrm{S-J}*}}{\partial\theta} > 0$, $\frac{\partial p^{\mathrm{S-J}*}}{\partial\rho} > 0$; $\frac{\partial w^{\mathrm{S-J}*}}{\partial\rho} > 0$, $\frac{\partial w^{\mathrm{S-J}*}}{\partial\theta} > 0$, $\frac{\partial w^{\mathrm{S-J}*}}{\partial e_s} > 0$; $\frac{\partial x^{\mathrm{S-J}*}}{\partial\theta} > 0$, $\frac{\partial x^{\mathrm{S-J}*}}{\partial\rho} > 0$, $\frac{\partial x^{\mathrm{S-J}*}}{\partial e_f} > 0$. (ii) From Propositions 5.3 to 5.4 we can get that $\frac{\partial\pi_f^{\mathrm{S-B}*}}{\partial\theta} = \frac{\alpha+\theta+\rho-\varepsilon(c_b+\varphi(c_f+c_s))}{8\varepsilon} - k\theta$, let $\theta_2 = \frac{\alpha+\rho-\varepsilon(c_b+\varphi(c_f+c_s))}{8k\varepsilon-1}$, so, when $\theta > \theta_2$, $\frac{\partial\pi_f^{\mathrm{S-B}*}}{\partial\theta} > 0$. Similarly, combining $D_2^{\mathrm{S-B}*} = \frac{\alpha+\theta+\rho-\varepsilon(c_b+\varphi(c_f+c_s))}{4} > 0$, we can get that $\frac{\partial\pi_s^{\mathrm{S-B}*}}{\partial\theta} = \frac{\alpha+\theta+\rho-\varepsilon(c_b+\varphi(c_f+c_s))}{4\varepsilon} > 0$. Similarly, we can get $\frac{\partial D_2^{\mathrm{S-B}*}}{\partial\theta} > 0$. (iii) From Propositions 5.3 to 5.4, we can get that $\frac{\partial\pi_f^{\mathrm{S-B}*}}{\partial c_b} = \frac{-\alpha-\theta-\rho+\varepsilon(c_b+\varphi(c_f+c_s))}{8} < 0$, $\frac{\partial\pi_s^{\mathrm{S-B}*}}{\partial c_b} = \frac{-\alpha-\theta-\rho+\varepsilon(c_b+\varphi(c_f+c_s))}{4} < 0$, $\frac{\partial\pi_f^{\mathrm{S-B}*}}{\partial\varepsilon} = -\frac{(\alpha+\theta+\rho+\varepsilon(c_b+\varphi(c_f+c_s)))(\alpha+\theta+\rho-\varepsilon(c_b+\varphi(c_f+c_s)))}{16\varepsilon^2} < 0$, $\frac{\partial\pi_s^{\mathrm{S-B}*}}{\partial\varepsilon} = -\frac{(\alpha+\theta+\rho+\varepsilon(c_b+\varphi(c_f+c_s)))(\alpha+\theta+\rho-\varepsilon(c_b+\varphi(c_f+c_s)))}{8\varepsilon^2} < 0$, $\frac{\partial\pi_f^{\mathrm{S-B}*}}{\partial\rho} = \frac{(\alpha+\theta+\rho-\varepsilon(c_b+\varphi(c_f+c_s)))}{8\varepsilon} > 0$, $\frac{\partial\pi_s^{\mathrm{S-B}*}}{\partial\rho} = \frac{(\alpha+\theta+\rho-\varepsilon(c_b+\varphi(c_f+c_s)))}{4\varepsilon} > 0$. □

Proof of Proposition 5.6. Compare the Model B and Model J, we can get (i) From Propositions 5.3 to 5.4, and $D_2^{\mathrm{S-J}*} = \frac{\alpha-c_b\varepsilon+\theta+\rho-\varepsilon(c_m+\varphi c_f+\varphi c_s)}{8} > 0$, we can get that $D_2^{\mathrm{S-B}*} - D_2^{\mathrm{S-J}*} = \frac{\alpha+\theta+\rho-\varepsilon(c_b-c_m+\varphi c_f+\varphi c_s)}{8} > 0$, so, $D_2^{\mathrm{S-B}*} > D_2^{\mathrm{S-J}*}$. $p^{\mathrm{S-J}*} - p^{\mathrm{S-B}*} = \frac{\alpha-c_b\varepsilon+\theta+\rho+\varepsilon(c_m-\varphi c_f-\varphi c_s)}{8\varepsilon} > 0$, so, $p^{\mathrm{S-B}*} < p^{\mathrm{S-J}*}$. $w^{\mathrm{S-J}*} - w^{\mathrm{S-B}*} = -\frac{c_m}{2} < 0$, so, $w^{S-B*} > w^{\mathrm{S-J}*}$. (ii) From Propositions 5.3 to 5.4, we can get that $\frac{\pi_s^{\mathrm{S-J}*}}{\pi_s^{\mathrm{S-B}*}} = \frac{(\alpha-c_b\varepsilon+\theta+\rho-\varepsilon(c_m+\varphi c_f+\varphi c_s))^2}{2(\alpha+\theta+\rho-\varepsilon(c_b+\varphi c_f+\varphi c_s))^2} < 1$, so, $\pi_s^{\mathrm{S-B}*} > \pi_s^{\mathrm{S-J}*}$. $\pi_m^{\mathrm{S-J}*} - \pi_f^{\mathrm{S-B}*} = \frac{(\alpha-c_b\varepsilon+\theta+\rho-\varepsilon(c_m+\varphi c_f+\varphi c_s))^2-4(\alpha+\theta+\rho-\varepsilon(c_b+\varphi c_f+\varphi c_s))^2}{64\varepsilon} < 0$, so, $\pi_f^{\mathrm{S-B}*} > \pi_m^{S-J*}$. (iii) $\pi_s^{\mathrm{S-B}*} - \pi_f^{\mathrm{S-B}*} = \frac{(\alpha+\theta+\rho-\varepsilon(c_b+\varphi c_f+\varphi c_s))^2+8k\varepsilon\theta^2}{16\varepsilon} > 0$, $\frac{\pi_s^{\mathrm{S-J}*}}{\pi_f^{\mathrm{S-J}*}} = 2$. □

Proof of Proposition 5.7. We analyze the case of Nash game. Then, given $p = w + m$, the optimization problems of the FFC reduced to: $\pi_f^{\mathrm{N-B}} = (\alpha - (w+m)\varepsilon + \theta + \rho)((w+m) - c_b - w + e_s - \varphi c_f) - \frac{k\theta^2}{2}$. The Nash equilibrium decision can be obtained by solving the system of equations derived from the first-order conditions: $\frac{\partial \pi_f^{\mathrm{N-B}*}}{m} = 0$, $\frac{\partial \pi_s^{\mathrm{N-B}*}}{w} = 0$. Then, we can get that $m^{\mathrm{N-B}*} = \frac{\alpha+2c_b\varepsilon+\theta+\rho+2\varepsilon\varphi c_f-\varepsilon(3e_s+\varphi c_s)}{3\varepsilon}$, $w^{\mathrm{N-B}*} = \frac{\alpha-c_b\varepsilon+\theta+\rho-\varepsilon\varphi c_f+\varepsilon(3e_s+2\varphi c_s)}{3\varepsilon}$, So, we can get $p^{\mathrm{N-B}*} = \frac{2\alpha+c_b\varepsilon+2\theta+2\rho+\varepsilon\varphi c_f+\varepsilon\varphi c_s}{3\varepsilon}$. Substituting $w^{\mathrm{N-B}*}$ and $p^{\mathrm{N-B}*}$ into the demand and profit functions, we can obtain $D_2^{\mathrm{N-B}*} = \frac{\alpha-c_b\varepsilon+\theta+\rho-\varepsilon\varphi(c_f+c_s)}{3}$, $\pi_s^{\mathrm{N-B}*} = \frac{(\alpha-c_b\varepsilon+\theta+\rho-\varepsilon\varphi(c_f+c_s))^2}{9\varepsilon}$, $\pi_f^{\mathrm{N-B}*} = \frac{(\alpha-c_b\varepsilon+\theta+\rho-\varepsilon\varphi(c_f+c_s))^2}{9\varepsilon} - \frac{k\theta^2}{2}$. □

Proof of Proposition 5.8. Similar to the Proof of Proposition 5.7 (Q.E.D.) □

Proof of Proposition 5.9. From Propositions 5.7 to 5.8, we can get that (i) $D_2^{\mathrm{N-B}*} - D_2^{\mathrm{N-J}*} = \frac{\alpha+\theta+\rho-\varepsilon(c_b+\varphi c_f+\varphi c_s)}{12} > 0$, so, $D_2^{\mathrm{N-B}*} > D_2^{\mathrm{N-J}*}$. $p^{\mathrm{N-B}*} - p^{\mathrm{N-J}*} = -\frac{\alpha-c_b\varepsilon+\theta+\rho+\varepsilon(3c_m-\varphi(c_f+c_s))}{12\varepsilon} < 0$, so, $p^{\mathrm{N-B}*} < p^{N-J*}$, $w^{\mathrm{N-B}*} - w^{\mathrm{N-J}*} = \frac{\alpha-c_b\varepsilon+\theta+\rho+\varepsilon(3c_m-\varphi(c_f+c_s))}{12\varepsilon} > 0$, so, $w^{\mathrm{N-B}*} > w^{\mathrm{N-J}*}$. (ii) $\pi_S^{\mathrm{N-B}*}/\pi_s^{\mathrm{N-J}*} = \frac{16(\alpha-c_b\varepsilon+\theta+\rho-\varepsilon\varphi(c_f+c_s))^2}{9(\alpha+\theta+\rho-\varepsilon c_b-\varepsilon(c_m+\varphi c_f+\varphi c_s))^2} > 1$, so, $\pi_s^{\mathrm{N-B}*} > \pi_s^{\mathrm{N-J}*}$. $\pi_f^{\mathrm{N-B}*} - \pi_m^{N-J*} = \frac{16(\alpha-c_b\varepsilon+\theta+\rho-\varepsilon\varphi(c_f+c_s))^2-9(\alpha+\theta+\rho-\varepsilon c_b-\varepsilon(c_m+\varphi c_f+\varphi c_s))^2}{144\varepsilon} > 0$, so, $\pi_f^{\mathrm{N-B}*} > \pi_m^{\mathrm{N-J}*}$. (iii) $\pi_s^{\mathrm{N-B}*} - \pi_f^{\mathrm{N-B}*} = \frac{k\theta^2}{2}$, so, $\pi_s^{\mathrm{N-B}*} > \pi_f^{\mathrm{N-B}*}$. $\frac{\pi_s^{\mathrm{N-J}*}}{\pi_f^{\mathrm{N-J}*}} = 1$, so, $\pi_s^{N-J*} = \pi_f^{\mathrm{N-J}*}$. □

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