sustainability

MDPI

Article

The Optimal Logistics Distribution Service Strategy of the E-commerce Closed-Loop Supply Chain Network under Blockchain Technology and the Government Blockchain Subsidy

Yan Zhou [1,*], Cong Liang [1] and Kar-Hung Wong [2]

[1] Business School, Qingdao University, Qingdao 266071, China; lc121140@163.com
[2] School of Computer Science and Applied Mathematics, University of the Witwatersrand, Johannesburg 2000, South Africa; karwong01@gmail.com
* Correspondence: yanzhou@qdu.edu.cn

Abstract: The booming development of e-commerce has promoted the diversified development of logistics distribution services (LDS). For LDS, e-commerce retailers (e-retailers) often choose either the outsourced logistics distribution services strategy (OLDSS) or the self-built logistics distribution services strategy (SBLDSS). Although there are problems such as products getting lost and damaged during the logistics distribution process, the high transparency and traceability characteristics of blockchain technology (BT) can help solve the problem of products being lost and damaged in the logistics distribution process. However, due to the high cost of BT, e-retailers may encounter reduced sales, which causes the supply chain corporate profits to decrease. To encourage the BT investment enthusiasm of the e-retailers and regulate corporate profits, the government implements subsidies for e-retailers' BT, namely, the government blockchain subsidy (GBS). In addition, in recent years, environmental degradation has become increasingly severe, causing negative impacts on people's lives. To promote sustainable development, we use variational inequality to establish an e-commerce closed-loop supply chain (E-CLSC) network equilibrium model in which the network equilibrium decisions of e-retailers choosing the OLDSS and those choosing the SBLDSS are obtained. Then, we analyze the impact of the BT input cost and the GBS quota on equilibrium decisions by studying their properties and verifying the theoretical results by performing numerical examples. Finally, we analyze the profits of the e-retailers to obtain the impact of the BT input cost and the GBS quota on e-retailers' choice of the optimal LDS strategy; in this way, we provide a scientific basis for e-retailers to choose the optimal LDS strategy. The results show that increasing the BT input costs reduces e-retailers' product sales under the two LDS strategies, which decreases the production rate and the recovery rate of the products. When the BT input cost is low, SBLDSS is the best choice for e-retailers. When the BT input cost is high, OLDSS is the best choice for e-retailers. Moreover, there is a positive correlation between GBS and e-retailers' product sales; thus, GBS is conducive to expanding market demand, regulating the profits of manufacturers, increasing the e-retailers' profits, improving the enthusiasm of the e-retailers for BT investment, and promoting the overall development of supply chain enterprises. For e-retailers, choosing the OLDSS can lead to a better development of the E-CLSC.

Keywords: e-commerce; closed-loop supply chain network; logistics distribution services; blockchain technology; government subsidy; sustainability

check for updates

Citation: Zhou, Y.; Liang, C.; Wong, K.-H. The Optimal Logistics Distribution Service Strategy of the E-commerce Closed-Loop Supply Chain Network under Blockchain Technology and the Government Blockchain Subsidy. *Sustainability* **2024**, *16*, 6294. https://doi.org/10.3390/su16156294

Academic Editor: Giada La Scalia

Received: 7 June 2024
Revised: 6 July 2024
Accepted: 16 July 2024
Published: 23 July 2024

1. Introduction

As a consequence of the rapid development of the Internet, e-commerce has gradually become an important business model throughout the world. Due to the rapid growth of e-commerce, many well-known e-commerce retailers (e-retailers) have established their business in China, such as Tmall (Chian), JD (China), Vipshop (China), and Poizon (China), and the logistics distribution services (LDS) have also gradually developed. The XNA report shows that, in 2023, the cumulative volume of parcels delivered by China Post reached 24.702 million pieces, an increase of 40.6% compared to the same period in 2022 [1]. In China, the LDS strategies often chosen by e-retailers include outsourced LDS strategy (OLDSS) [2], self-built LDS strategy (SBLDSS) [3], and hybrid logistics distribution service strategy (hybrid LDS strategy) [4]. OLDSS refers to e-retailers outsourcing their LDS to third-party logistics distribution providers (3PLDPs), such as Yuantong (China), Shentong (China), Zhongtong (China), and Yunda (China) [5], for product distribution. In this way, e-retailers can focus more on their sales business by choosing the OLDSS. On the other hand, due to the characteristics of high control and strong serviceability of SBLDSS, SBLDSS has gradually increased its popularity in recent years. Since e-retailers can obtain more benefits from SBLDSS [6], more and more e-retailers have established SBLDSS systems, such as JD (China), Suning (China), and Amazon (USA), and have established their own LDS systems and relied on the service of their own LDS systems to deliver their products to demand markets [3]. Compared with the OLDSS, the SBLDSS can deliver on time, improve service quality, and enhance corporate brand value [7], but it also faces pressures such as high service cost, low distribution efficiency, and limited scale [8]. OLDSS and SBLDSS, as two mainstream LDS strategies, have a significant impact on the development of the logistics economy. Therefore, it is of great significance to analyze which LDS strategy should be used by the e-retailers to increase their profits.

Although the development of China's LDS industry has been relatively mature, the proportion of products getting lost and damaged during the logistics distribution process remains high. Blockchain technology (BT), as a decentralized distributed ledger database technology, has the characteristics of decentralization, data traceability, data being unable to be tampered with, data security and trustworthiness, etc. It can effectively avoid data fraud and carry out product traceability [9–11]. The introduction of BT in the logistics distribution process helps to improve the transparency, reliability, and security of the logistics distribution process. For example, Walmart's (USA) fresh goods supplier uses BT to record the product transfer process [12], and JD cooperates with Australia's InterAgri Group to develop a blockchain platform to track the transportation and other processes of imported Angus beef [12]. In addition, because BT can achieve precise accountability for damaged products [13], BT is conducive to reducing the proportion of products that are being damaged and lost during logistics distribution [14]. Although BT can ensure the safety of the product logistics distribution process, the high BT cost will dampen the investment enthusiasm of the enterprises [15]. To support the development of BT, the government provides subsidies to e-retailers' BT investments to regulate corporate profits and increase corporate enthusiasm for BT investment [15]. Some government agencies also have taken measures to subsidize BT; for example, the UK government has promised to provide GBP 19 million to financially support its BT companies' investments [16].

The advantage of a closed-loop supply chain (CLSC) is that it can realize product recycling and remanufacturing at the back end of the recycling process [17], which has made outstanding contributions in reducing cost, improving efficiency, and promoting sustainable production. The CLSC network equilibrium model [18] can describe Nash's non-cooperative competition behavior [19] with multiple competitors on the same level, which is consistent with reality. Therefore, many scholars use CLSC network equilibrium to study heterogeneous products with different market demands [20], as well as green supply chain technology investment problems [21,22], the cap-and-trade regulation problem [23], the production strategy problem of global supply chains [24], and the impact of government subsidies on recovery amount [25], etc., but there is no research on the optimal LDS strategy problem of e-retailers. Due to the rapid development of e-commerce, CLSC's sales activities have opened online channels. Therefore, this paper extends the CLSC network equilibrium to the e-commerce mode, that is, the e-commerce CLSC (E-CLSC) network, in which e-retailers apply BT in two LDS strategies, i.e., OLDSS and SBLDSS, to track and supervise the logistics distribution process to ensure the smooth delivery of products to customers. In this way, the government increases e-retailers' BT investment enthusiasm by subsidizing e-retailers.

In this paper, we use variational inequality (VI) under two LDS strategies to establish an E-CLSC network equilibrium model considering e-retailers' BT input cost and GBS quota. We qualitatively analyze the impact of BT input cost and GBS quota on e-retailer's equilibrium decisions and conduct quantitative analysis through examples. By comparing and analyzing the profits of e-retailers under two LDS strategies, we determine the optimal LDS strategy for e-retailers, which provides a scientific basis for e-retailers to choose the optimal LDS strategy. The contributions of this article are as follows:

(1) We analyze the logistics distribution process of e-retailers in the E-CLSC network, in which e-retailers use BT to supervise their businesses. We also analyze how the government subsidizes e-retailers' BT investments to increase their BT investment enthusiasm and regulate corporate profits.
(2) We establish an E-CLSC network equilibrium model in which e-retailers either choose the OLDSS or the SBLDSS and obtain the E-CLSC network equilibrium decisions by using VI.
(3) We analyze the impact of BT input cost and GBS quota on the equilibrium decisions of the two LDS strategies through properties analysis and verify this by solving numerical examples. Furthermore, by comparing and analyzing the profits of e-retailers, we obtain the impact of BT input cost and GBS quota on e-retailers' choices of different LDS strategies. In this way, we understand how e-retailers should choose the best LDS strategy based on different BT input costs and GBS quotas.

The rest of this paper is structured as follows: Section 2 concerns the literature review; Section 3 concerns the research methodology; Section 4 concerns the model description and its related assumptions; Sections 5 and 6 construct the e-retailers' OLDSS and SBLDSS equilibrium models, respectively, and analyze the BT input cost and GBS quota through properties analysis; Section 7 uses numerical analysis to verify the impact of BT input cost and the GBS quota on equilibrium decisions and obtain e-retailers' optimal LDS strategy; and Section 8 provides the conclusion.

2. Literature Review

This section focuses on five aspects: CLSC network equilibrium, LDS strategy, BT, GBS, and research methodology.

2.1. Closed-Loop Supply Chain Network Equilibrium

The CLSC network equilibrium problem describes the competing behavior of multiple members of the same layer [18,19], which has the advantages of saving resources and promoting sustainable production. Therefore, this problem is widely used in CLSC management. Yang et al. [26] used VI to establish a CLSC network equilibrium considering suppliers. Qiang et al. [27] established the CLSC network equilibrium considering uncertainties in demand to analyze the impact of expected yield rate on equilibrium decisions. Chan et al. [28] used a dynamic CLSC network equilibrium model to study the problem of the seasonality of demand. The effect of carbon policies on the results of CLSC network equilibrium was studied in Refs. [29,30]. Zhou et al. [31] studied the optimal remanufacturing strategy of the CLSC network. However, the impact of the BT input cost and the GBS quota on LDS strategy has not been analyzed in the existing literature. Furthermore, due to the development of e-commerce, the study of the E-CLSC network has become a trend in CLSC management. Therefore, it is necessary to analyze the influence of BT input cost and GBS quota on the E-CLSC network equilibrium and the optimal LDS strategy.

2.2. Logistics Distribution Services Strategy

With the development of e-commerce, the LDS strategy has also diversified, in such a way that OLDSS and SBLDSS have been widely studied as two mainstream delivery models. Giri and Sarker [32] found that OLDSS has a significant impact on supply chain performance. Challenged by the omnichannel retail model, Bulde et al. [33] tried to find a way for 3PLDPs to participate in the supply chain. Liu et al. [34] analyzed the interaction between the LDS strategy and the platform sales model in the B2C e-commerce model. For the case of multiple types of 3PLDPs, Cao et al. [35] studied the LDS strategies of brands when selling products on e-commerce platforms. The results of the study showed that the choice of LDS contractors is related to the service level and the cost difference between e-retailers and 3PLDPs. Dong et al. [36] studied how manufacturers can choose an LDS strategy for two types of logistics companies with green-washing. Wang et al. [37] found that logistics competitions play an important role in the selection of the LDS strategies of manufacturers, using the SBLDSS when the logistics level gap is small and the OLDSS when the logistics level gap is large. However, the above literature analyzes the LDS strategy in the forward supply chain. Different from the above studies, this paper analyzes the optimal LDS strategy for e-retailers by establishing the E-CLSC network equilibrium model.

2.3. Blockchain Technology

BT is an emerging technology that can ensure product quality and enable product traceability and anti-counterfeiting. The current classification of blockchain includes public blockchain, consortium blockchain, and private blockchain, which are suitable for different scenarios [38]. Consortium blockchain is widely used in supply chains, and many scholars have researched the application of BT. In the case of food supply chains, Modak et al. [39] studied the optimal decision making and profitability of fresh agricultural product supply chains considering BT. In the case of supply chain finance, Wang et al. [40] found that BT has a regulatory role for green loans and is conducive to improving the environment. In the case of medical treatment, Niu et al. [41] found that BT can be used in the pharmaceutical industry to improve drug safety and solve drug safety issues. Moreover, as the patient records are scattered and inconvenient for information sharing, BT is used to achieve patient record sharing and improve medical transparency and efficiency [42]. In terms of information disclosure, Zhang et al. [43] found that BT influenced product quality-related information. In terms of recycling and remanufacturing, Wang et al. [44] used BT in the reverse supply chain to reduce consumers' perceived risk of remanufacturing and found that it was easier to achieve a win–win situation when the unit blockchain cost was not high. In the textile and apparel industry, Zhang et al. [45] found that BT has great potential in mitigating environmental pollution. In addition, Dai et al. [46] studied the traceability of BT by tracing the cost coefficient and found that investment traceability can improve product reliability. Existing research suggests that the application of BT in multiple industries can have a beneficial impact. However, few researchers have analyzed the effect of BT on the optimal LDS strategy. In this paper, the investment cost of BT for e-retailers is determined by both BT input cost and product transaction volume, according to [46], and the impact of BT input cost on the LDS strategy for e-retailers is studied.

2.4. Government Blockchain Subsidy

BT has an advantage in terms of providing regulatory records, but the higher cost involved reduces the willingness of supply chain members to invest in it. Zhong et al. [16] found that implementing an innovation subsidy and quantity subsidy for blockchain technology can create higher social welfare. Wang et al. [47] found that, in the maritime industry, the relationship between the unit net benefit and the unit operating cost of BT is crucial to the successful application of BT. Therefore, when the government provides a subsidy for BT, the enterprises are more willing to invest in it; this issue has been studied by many scholars. Zhang et al. [48] discussed the application of BT in the construction industry and found that the implementation of government subsidies for BT was beneficial in terms of improving the perceived values of BTs among stakeholders, thereby promoting the use of BT. Hamidoğlu et al. [49] studied how the government can control the agricultural product market based on providing subsidies for BT and found that subsidies incentivize the application of blockchain technology. The above literature shows that when BT is applied in different fields, the government subsidy always has an incentive effect on the enterprises' willingness to use BT. Thus, this paper considers how the government subsidy for e-retailers can encourage them to invest in BT.

The above literature considers some of the CLSC networks, LDS strategies, blockchain, and government subsidies; however, with the innovation of technology and the continuous development of e-commerce and LDS, these studies can no longer meet the development needs of modern enterprises. Therefore, this paper studies the optimal LDS strategy considering BT input cost and GBS quota to provide a basis for the scientific decision-making processes of e-retailers to choose the optimal LDS strategy. Table 1 shows the differences between this study and those in the existing literature.

Table 1. Literature innovation.

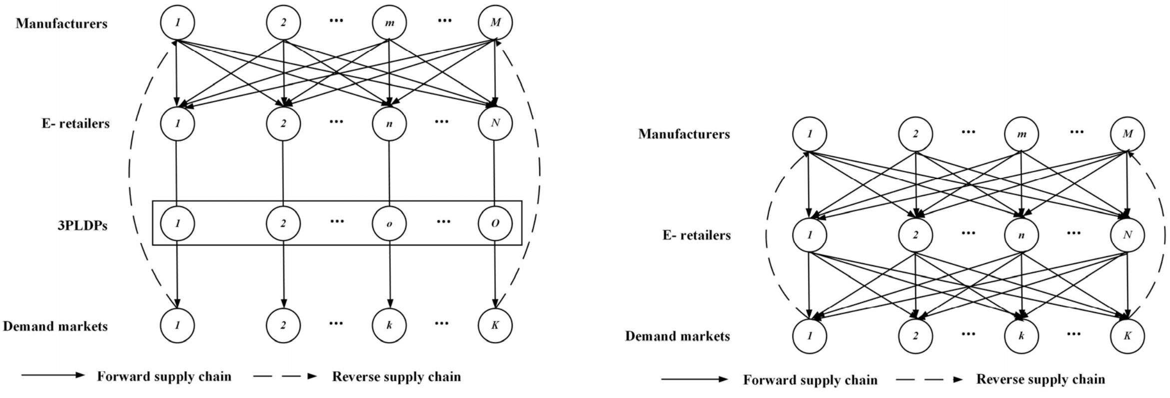
Reference	CLSC Network	Outsourced LDS	Self-Built LDS	BT	Government Subsidy
Hammond and Beullens (2007) [18]	√				
Yang et al. (2009) [26]	√				
Qiang et al. (2013) [27]	√				
Yang et al. (2021) [29]	√				
Cheng et al. (2023) [30]	√				√
He et al. (2019) [5]		√			
Zheng et al. (2020) [3]		√	√		
Wang et al. (2022) [37]		√	√		
Yu et al. (2024) [6]			√		
Choi and Luo. (2019) [15]				√	√
Zhou et al. (2023) [31]	√				√
Dong et al. (2023) [36]		√		√	
Hou et al. (2024) [10]				√	
Zhang et al. (2023) [48]				√	√
Hamidoğlu et al. (2024) [49]				√	√
This study	√	√	√	√	√

3. Research Methodology

In this paper, we establish an E-CLSC network equilibrium by using the theory of the Nash Non-Cooperative Game [19], considering the BT input cost and GBS quota. We first obtain the network equilibrium decision of the e-retailers choosing OLDSS, then the E-CLSC network equilibrium decision of the e-retailers choosing SBLDSS. The impact of the BT input cost and the GBS quota on the equilibrium decisions is analyzed qualitatively using property analysis, and it is quantitatively studied by solving numerical examples under the two LDS strategies. By comparing and analyzing the profits of e-retailers under the two LDS strategies, the impact of the BT input cost and the GBS quota on the optimal LDS strategy of the e-retailers is determined, which provides a scientific basis for e-retailers to choose the optimal LDS strategy.

4. Model Description and Assumptions

In the E-CLSC network of this paper, e-retailers consider two LDS strategies, namely, the OLDSS and the SBLDSS, respectively. The CLSC network of the OLDSS consists of M competing manufacturers, N competing e-retailers, O competing 3PLDPs, and K demand markets, as shown in Figure 1a, where 3PLDPs undertake the distribution tasks outsourced by e-retailers for delivering products to the demand markets. On the other hand, the CLSC network of the SBLDSS network consists of M competing manufacturers, N competing e-retailers, and K demand markets, as shown in Figure 1b, where the retailers deliver their own products to the demand markets. In order to reduce the proportion of damage to the products in the logistics distribution process, e-retailers invest in BT to retrospectively supervise the logistics distribution processes of the products they sell, thus incurring BT investment costs. The BT investment cost is closely related to the BT input cost and product transaction volume [46]. Due to the high cost of BT investment, which will affect the use of BT by e-retailers, the government provides a certain amount of BT subsidy for each unit of product sold by e-retailers [16] to increase the e-retailers' enthusiasm for BT investment.



(a) (b)

Figure 1. The CLSC network. (**a**) The CLSC network under the OLDSS; (**b**) The CLSC network under the SBLDSS.

Under OLDSS, the decision variables are shown in Table 2.

Table 2. Decision variables under the OLDSS.

Variable	Significance
q_m^{new}	The number of new products produced by manufacturer m. All these newly manufactured products form a vector $Q^1 \in R_+^M$.
q_{mn}	The number of products sold by e-retailer n from manufacturer m. All these sold products form a matrix $Q^2 \in R_+^{MN}$.
q_{nok}	The number of products sold by e-retailer n to demand market k via 3PLD o. All these sold products form a three-dimensional tensor $Q^3 \in R_+^{NOK}$.
r_{nok}	The unit transportation cost incurred by 3PLDPo. All these transportation costs form a vector $R \in R_+^{NOK}$.
q_{km}	The number of scrap products recovered by manufacturer m from demand market k. All these recycling products form a matrix $Q^4 \in R_+^{KM}$.
ρ_k	The retail price of demand market k. All these retail prices form a vector $\rho \in R_+^K$.

Under SBLDSS, the other decision variable is shown in Table 3.

Table 3. Decision variable under the SBLDSS.

Variable	Significance
q_{nk}	The number of products sold by e-retailer n to the demand market k. All these sold products form a vector $Q^5 \in R_+^{NK}$.

The parameters are shown in Table 4.

Table 4. Parameters.

Parameter	Significance
α	The recycling rate of wasted products
β	The remanufactured rate of recycled products
η	The unit disposal cost of wasted products
θ	The BT input cost
s_B	The GBS quota

We need the following assumptions:

Assumption 1. *Only a single production cycle is considered [50].*

Assumption 2. *Since this paper considers the e-commerce retail model, all information is open and transparent, and the information of the decision makers in the E-CLSC network is completely symmetrical [50].*

Assumption 3. *All the members in each layer are competing non-cooperatively in the Nash manner [19].*

Assumption 4. *The remanufactured product and the new product are homogeneous, and the production cost of the remanufactured product is lower than that of the new product [50].*

Assumption 5. *To reduce the proportion of damage in the logistics distribution process, e-retailers invest in BT to supervise the logistics distribution process of the products they sell, and the BT investment cost is an increasing function of the BT input cost* θ *[46], that is, the investment cost* $isc_{n,B}\left(\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K} q_{nok}, \theta\right)$.

Assumption 6. *Due to the high cost of BT investment, the government provides a subsidy for each unit of product sold by e-retailers, and the subsidy amount is an increasing function of the sales quantity [16].*

Assumption 7. *The cost function is a continuous, differentiable, and convex function of the decision variable, and the demand function is a subtraction function of the price variable [18].*

5. Equilibrium of the E-CLSC under the OLDSS

In this section, we consider the E-CLSC network model under the OLDSS For example, Taobao, a well-known e-commerce platform in China, adopts OLDSS [51]. In Figure 1a, manufacturer m $(m = 1, \cdots, M)$ produces a new product and sells it to e-retailer n $(n = 1, \cdots, N)$ with a transaction quantity q_{mn}; e-retailer n $(n = 1, \cdots, N)$ then sells these products to demand market k $(k = 1, \cdots, K)$ via 3PLDPo $(o = 1, \cdots, O)$ with the transaction quantity q_{nok} and the total sales quantity $\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K} q_{nok}$. Demand market k $(k = 1, \cdots, K)$ recycles these products and sends them to manufacturer m $(m = 1, \cdots, M)$ with the transaction quantity q_{km} $(k = 1, \cdots, K; m = 1, \cdots, M)$. Figure 2 shows the transaction diagram under the OLDSS. Since the recording and traceability function of BT can reduce the proportion of products being lost and damaged in the logistics distribution process, e-retailers need to invest in BT with the investment cost $c_{n,B}\left(\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K} q_{nok}, \theta\right)$. Since the cost of BT investment is high, the government needs to encourage e-retailers to invest in BT by subsidizing them with a subsidy equal to s_B per unit product, and with the total subsidy equal to $s_B \sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K} q_{nok}$.

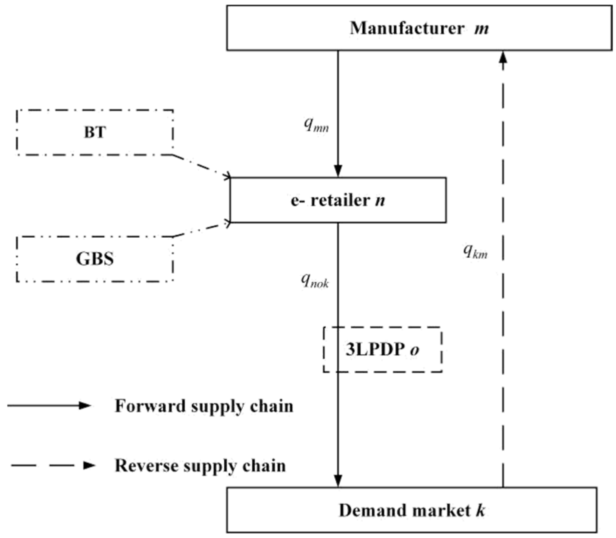


Figure 2. Transaction diagram under the OLDSS.

5.1. Manufacturers' Equilibrium Decisions under the OLDSS

M competing manufacturers manufacture new products and sell these products to N e-retailers. They also collect waste products from K demand markets for remanufacturing such that the remanufactured products and the new products are homogenous (Assumption 4). Thus, manufacturer $m(m = 1, \cdots, M)$ needs to determine the quantity of new product q_m^{New}; the product transaction quantity with e-retailer n $(n = 1, \cdots, N)$, q_{mn}; and the quantity of waste products recovered from demand market k $(k = 1, \cdots, K)$, q_{km}, in one production cycle. Thus, the revenue of manufacturer m $(m = 1, \cdots, M)$ in one production cycle is $\sum\limits_{n=1}^{N} \rho_{mn} q_{mn}$ (ρ_{mn} is the endogenous wholesale price), and its cost includes the production cost $f_m(Q^1)$, the transaction cost $\sum\limits_{n=1}^{N} c_{mn}(q_{mn})$, the recovery cost $\sum\limits_{k=1}^{K} \rho_{km} q_{km}$ (ρ_m is the endogenous recovery price), the recovery transaction cost $\sum\limits_{k=1}^{K} c_{km}(q_{km})$, the inspection and cleaning cost for recycled waste products $c_m(\sum\limits_{k=1}^{K} q_{km})$, the remanufacturing cost $\varphi_m(\beta \sum\limits_{k=1}^{K} q_{km})$, the disposal cost for unusable waste products $\eta(1-\beta)\sum\limits_{k=1}^{K} q_{km}$, and the transportation cost for unusable wasted products $c_{m,D}\left((1-\beta)\sum\limits_{k=1}^{K} q_{km}\right)$. Let the net profit of manufacturer m $(m = 1, \cdots, M)$ in one production cycle of the OLDSS be π_m. Then, the maximization problem of manufacturer m in this model is:

$$\begin{aligned} \max \pi_m = & \sum_{n=1}^{N} \rho_{mn} q_{mn} - f_m(Q^1) - \sum_{n=1}^{N} c_{mn}(q_{mn}) - \sum_{k=1}^{K} \rho_{km} q_{km} - \sum_{k=1}^{K} c_{km}(q_{km}) - c_m\left(\sum_{k=1}^{K} q_{km}\right) \\ & -\phi_m\left(\beta \sum_{k=1}^{K} q_{km}\right) - \eta(1-\beta)\sum_{k=1}^{K} q_{km} - c_{m,D}\left((1-\beta)\sum_{k=1}^{K} q_{km}\right) \end{aligned} \tag{1}$$

$$\text{s.t.} \sum_{n=1}^{N} q_{mn} \le q_m^{new} + \beta \sum_{k=1}^{K} q_{km} \tag{2}$$

$$\begin{gathered} \alpha \sum_{n=1}^{N} q_{mn} \le \sum_{k=1}^{K} q_{km} \\ q_m^{new}, q_{mn}, q_{km} \ge 0 \forall n, k. \end{gathered} \tag{3}$$

Constraint (2) indicates that the quantity of products sold by manufacturer m is not more than the sum of the quantities of new and remanufactured products it produces, and Constraint (3) indicates that the amount of waste products must be recycled to meet the minimum recycling standards.

Proposition 1. *In view of Assumption 7, the profit of manufacturer m under the OLDSS,* π_m*, is a concave function of* q_m^{new}*,* q_{mn}*, and* q_{km}*.*

Proof. See Appendix A. □

Theorem 1. *In view of Assumption 3, the equilibrium decisions of M manufacturers under the OLDSS are obtained by solving the following VI [18]:*

Determine $\left(Q^{1*}, Q^{2*}, Q^{4*}\omega^*, \vartheta^*\right) \in R_+^{M+MN+KM+2M}$*, which satisfies:*

$$
\begin{aligned}
&\sum_{m=1}^{M}\left[\frac{\partial f_m\left(Q^{1*}\right)}{\partial q_m^{new}}-\omega_m^*\right]\times\left[q_m^{new}-q_m^{new*}\right]\\
&+\sum_{m=1}^{M}\sum_{n=1}^{N}\left[\frac{\partial c_{mn}\left(q_{mn}^*\right)}{\partial q_{mn}}+\omega_m^*+\alpha\vartheta_m^*-\rho_{mn}^*\right]\times\left[q_{mn}-q_{mn}^*\right]\\
&+\sum_{k=1}^{K}\sum_{m=1}^{M}\left[\begin{array}{l}\rho_{km}^*+\dfrac{\partial c_{km}\left(q_{km}^*\right)}{\partial q_{km}}+\dfrac{\partial c_m\left(\sum\limits_{k=1}^{K}q_{km}^*\right)}{\partial q_{km}}+\dfrac{\partial \phi_m\left(\beta\sum\limits_{k=1}^{K}q_{km}^*\right)}{\partial q_{km}}\\ +\eta(1-\beta)+\dfrac{\partial c_{m,D}\left((1-\beta)\sum\limits_{k=1}^{K}q_{km}^*\right)}{\partial q_{km}}-\beta\omega_m^*-\vartheta_m^*\end{array}\right]\times\left[q_{km}-q_{km}^*\right]\\
&+\sum_{m=1}^{M}\left[q_m^{new*}+\beta\sum_{k=1}^{K}q_{km}^*-\sum_{n=1}^{N}q_{mn}^*\right]\times\left[\omega_m-\omega_m^*\right]\\
&+\sum_{m=1}^{M}\left[\sum_{k=1}^{K}q_{km}^*-\alpha\sum_{n=1}^{N}q_{mn}^*\right]\times\left[\vartheta_m-\vartheta_m^*\right]\geq 0,\forall\left(Q^1,Q^2,Q^4,\omega,\vartheta\right)\in R_+^{M+MN+KM+2M}.
\end{aligned}
\tag{4}
$$

where ω_m, ϑ_m *are the Lagrange multipliers of (2) and (3), respectively.*

Proof. See Appendix B. □

5.2. E-Retailers' Equilibrium Decisions under the OLDSS

N competing e-retailers obtain products from M manufacturers, outsource logistics distribution to all the 3PLDPs, and sell them to K demand markets through all the 3PLDPs. Hence, e-retailer n $(n=1,\cdots,N)$ needs to decide on the number of products purchased from manufacturer m $(m=1,\cdots,M)$, q_{mn}, and distribute them to demand market k $(k=1,\cdots,K)$ through 3PLDPo $(o=1,\cdots,O)$ with the transaction quantity q_{nok} in one production cycle. E-retailer n $(n=1,\cdots,N)$ needs to invest in BT with the invest cost,$c_{n,B}\left(\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K}q_{nok},\theta\right)$, and the government encourages it to invest in BT with the total subsidy equal to $s_B\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K}q_{nok}$. Thus, the income of e-retailers n $(n=1,\cdots,N)$ in one production cycle includes its revenue $\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K}\rho_{nok}q_{nok}$ (ρ_{nok} is the endogenous retail prices) and the government subsidy $s_B\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K}q_{nok}$, and its cost include the product purchase cost $\sum\limits_{m=1}^{M}\rho_{mn}q_{mn}$ (ρ_{mn} is the endogenous wholesale prices) and the logistics distribution cost $\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K}r_{nok}q_{nok}$ from all the 3PLDPs (r_{nok} is the purchase cost per unit of 3PLDPo's product); in addition, e-retailer n *is* also responsible for the payment of the product's display sales cost $c_n\left(Q^2\right)$ and the BT investment cost $c_{n,B}\left(\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K}q_{nok},\theta\right)$. Let the net profit of e-retailer n $(n=1,\cdots,N)$ in one production cycle of the OLDSS be π_n^{OL}. Then, the maximization problem of retailer n in this model is:

$$
\max\pi_n^{OL}=\sum_{o=1}^{O}\sum_{k=1}^{K}\rho_{nok}q_{nok}+s_B\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok}-\sum_{m=1}^{M}\rho_{mn}q_{mn}-\sum_{o=1}^{O}\sum_{k=1}^{K}r_{nok}q_{nok}-c_n\left(Q^2\right)-c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok},\theta\right)\tag{5}
$$

$$
\begin{gathered}
\text{s.t.}\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok}\leq\sum_{m=1}^{M}q_{mn}\\
q_{mn},q_{nok}\geq 0,\forall m,o,k
\end{gathered}
\tag{6}
$$

Constraint (6) indicates that the total quantity of products sold by e-retailer n does not exceed its total purchase quantity.

Proposition 2. *In view of Assumption 7, the profit of e-retailer n under the OLDSS,* π_n^{OL}*, is a concave function of* q_{mn} *and* q_{nok}*.*

Proof. The proof is the same as that of Proposition 1. □

Theorem 2. *In view of Assumption 3, the N e-retailers' equilibrium decisionsunder the OLDSS are obtained by thesolving the following VI [18]:*

Determine $\left(Q^{2*}, Q^{3*}, \sigma^*\right) \in R_+^{MN+NOK+N}$*, which satisfies:*

$$\begin{aligned}
&\sum_{m=1}^{M}\sum_{n=1}^{N}\left[\rho_{mn}^* + \frac{\partial c_n\left(Q^{2*}\right)}{\partial q_{mn}} - \sigma_n^*\right] \times \left[q_{mn} - q_{mn}^*\right] \\
&+ \sum_{n=1}^{N}\sum_{o=1}^{O}\sum_{k=1}^{K}\left[r_{nok}^* + \frac{\partial c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K} q_{nok}^*, \theta\right)}{\partial q_{nok}} + \sigma_n^* - \rho_{nok}^* - s_B\right] \times \left[q_{nok} - q_{nok}^*\right] \\
&+ \sum_{n=1}^{N}\left[\sum_{m=1}^{M} q_{mn}^* - \sum_{o=1}^{O}\sum_{k=1}^{K} q_{nok}^*\right] \times \left[\sigma_n - \sigma_n^*\right] \geq 0, \forall\left(Q^2, Q^3, \sigma\right) \in R_+^{MN+NOK+N}.
\end{aligned} \tag{7}$$

where σ_n *is the Lagrange multiplier of (6).*

Proof. The proof is the same as that of Theorem 1. □

Property 1. *In view of Assumptions 5–7, the decision variables of e-retailer n under the OLDSS,* q_{mn} *and* q_{nok}*, are decreasing functions of the BT input cost* θ *and increasing functions of the GBS quota* s_B*.*

Proof. See Appendix C. □

The interpretation of Property 1 from the economic point of view is as follows: As the e-retailers raise the input cost of BT, the investment cost of BT increases. Consequently, e-retailers, as rational decision makers, will decrease the quantity of product sales to reduce expenditure, and at the same time reduce the quantity of wholesale products to save costs. When the government subsidizes the BT of the e-retailers, part of the BT investment cost of the e-retailers will be deducted from the GBS. Consequently, the e-retailers will have sufficient funds, and they will expand the quantity of product sales to increase their profits.

5.3. PLDPs' Equilibrium Decisions under the OLDSS

O competing 3PLDPs undertake the logistics distribution business of N e-retailers for the transportation of their products to K demand markets. Hence, 3PLDPo $(o = 1, \cdots, O)$ needs to determine the transportation cost for each e-retailer n $(n = 1, \cdots, N)$ for the delivery of its products to demand market k $(k = 1, \cdots, K)$. Suppose that the transportation cost for delivering one item of a product from e-retailer n to demand market k is r_{nok}. Then, the total revenue for 3PLDPo is $\sum_{n=1}^{N}\sum_{k=1}^{K} r_{nok}q_{nok}$, and the total logistics distribution cost for 3PLDPo is $\sum_{n=1}^{N}\sum_{k=1}^{K} c_{nok}(r_{nok})$. Let the net profit of 3PLDPo $(o = 1, \cdots, O)$ in one production cycle of the OLDSS be π_o. Then, the maximization problem of 3PLDPo in this model is:

$$\begin{gathered}
\max \pi_o = \sum_{n=1}^{N}\sum_{k=1}^{K} r_{nok}q_{nok} - \sum_{n=1}^{N}\sum_{k=1}^{K} c_{nok}(r_{nok}) \\
r_{nok} \geq 0, \forall n, k
\end{gathered} \tag{8}$$

Proposition 3. *In view of Assumption 7, the net profit of 3PLDPo in the OLDSS,* π_o*, is a concave function of* r_{nok}*.*

Proof. See Appendix D. □

Theorem 3. *In view of Assumption 3, the O 3PLDPs' equilibrium decisions under the OLDSS are obtained by solving the following VI [18]:*

Determine $R^* \in R_+^{NOK}$*, which satisfies:*

$$\sum_{n=1}^{N}\sum_{o=1}^{O}\sum_{k=1}^{K}\left[\frac{\partial c_{nok}(r_{nok})}{\partial r_{nok}} - q_{nok}\right] \times [r_{nok} - r_{nok}^*] \geq 0, \forall R \in R_+^{NOK}. \tag{9}$$

Proof. The proof is the same as that of Theorem 1. □

5.4. Demand Markets' Equilibrium Decisions under the OLDSS

For the OLDSS, we need to consider the demand markets' equilibrium in both the forward supply chain and the reverse supply chain.

Suppose that in the forward supply chain, customers in demand market k $(k = 1, \cdots, K)$ are buying q_{nok} items of products from e-retailer n $(n = 1, \cdots, N)$ via 3PLDPo $(o = 1, \cdots, O)$ in one production cycle of the OLDSS and are willing to pay the price of ρ_k for the products they purchase. Then, the number of products purchased and the price that customers are willing to pay in demand market k $(k = 1, \cdots, K)$ must meet the following complementarity problems (CPs) [18]:

$$\rho_{nok}^* + \hat{c}_{nok}(q_{nok}^*)\begin{cases} = \rho_k^* \ if \ q_{nok}^* > 0 \\ \geq \rho_k^* \ if \ q_{nok}^* = 0, \end{cases} \tag{10}$$

and

$$d_k(\rho_k^*)\begin{cases} = \sum\limits_{n=1}^{N}\sum\limits_{o=1}^{O} q_{nok}^* \ if \ \rho_k^* > 0 \\ \leq \sum\limits_{n=1}^{N}\sum\limits_{o=1}^{O} q_{nok}^* \ if \ \rho_k^* = 0. \end{cases} \tag{11}$$

CP (10) indicates that when the quantity of purchased products from e-retailers n $(n = 1, \cdots, N)$ to demand market k $(k = 1, \cdots, K)$ via 3PLDPo $(o = 1, \cdots, O)$ is greater than zero, the price that the consumer is willing to pay is equal to the sum of the retail price and the transaction cost of the e-retailer. CP (11) indicates that when the consumer is willing to pay for the product, that is, when $\rho_k > 0$, the demand market k $(k = 1, \cdots, K)$ will reach an equilibrium between the supply and the demand.

In the reverse supply chain, suppose that manufacturer m $(m = 1, \cdots, M)$ collects q_{km} items of waste products from demand market k $(k = 1, \cdots, K)$ in one production cycle of the OLDSS. Suppose that the consumers' aversion to used products is $\alpha_k\left(Q^4\right)$. Then, the consumer behavior satisfies the following CP (12) [18]:

$$\alpha_k\left(Q^{4*}\right)\begin{cases} = \rho_{km}^* \ if \ q_{km}^* > 0 \\ \geq \rho_{km}^* \ if \ q_{km}^* = 0, \end{cases} \tag{12}$$

and

$$s.t. \sum_{m=1}^{M} q_{km} \leq \sum_{n=1}^{N}\sum_{o=1}^{O} q_{nok}. \tag{13}$$

CP (12) indicates that consumers of demand market k $(k = 1, \cdots, K)$ will return a portion of the waste products whose residual value is equivalent to the recycling price. Constraint (13) indicates that the quantity of waste products recycled in demand market k $(k = 1, \cdots, K)$ should not exceed the total amount of products in the market.

Theorem 4. *From the equivalence of CP (10–12) and VI [52], the K demand markets' equilibrium under the OLDSS is obtained by solving the following[18]:*

Determine $\left(Q^{3*}, Q^{4*}, \rho^*, \delta^*\right) \in R_+^{NOK+KM+2N}$ *which satisfies:*

$$\begin{aligned}
&\sum_{n=1}^{N}\sum_{o=1}^{O}\sum_{k=1}^{K}\left[\rho_{nok}^* + \hat{c}_{nok}\left(q_{nok}^*\right) - \rho_k^* - \delta_k^*\right] \times \left[q_{nok} - q_{nok}^*\right] \\
&+\sum_{k=1}^{K}\sum_{m=1}^{M}\left[\alpha_k\left(Q^{4*}\right) + \delta_k^* - \rho_{km}^*\right] \times \left[q_{km} - q_{km}^*\right] \\
&+\sum_{k=1}^{K}\left[\sum_{n=1}^{N}\sum_{o=1}^{O} q_{nok}^* - d_k\left(\rho_k^*\right)\right] \times \left[\rho_k - \rho_k^*\right] \\
&+\sum_{k=1}^{K}\left[\sum_{n=1}^{N}\sum_{o=1}^{O} q_{nok}^* - \sum_{m=1}^{M} q_{km}^*\right] \times \left[\delta_k - \delta_k^*\right] \geq 0, \forall\left(Q^3, Q^4, \rho, \delta\right) \in R_+^{NOK+KM+2N}.
\end{aligned} \tag{14}$$

where δ_k *is the Lagrange multiplier of (13).*

5.5. E-CLSC Networks' Equilibrium Decisions under the OLDSS

When all manufacturers, all e-retailers, all 3PLDPs, and all demand markets arrive at the equilibrium, then VI (4), VI (7), VI (9), and VI (14) will be satisfied simultaneously, which implies that the E-CLSC network has reached the equilibrium condition. By adding VI (4), VI (7), VI (9), and VI (14) and deleting the endogenous prices, we obtain the E-CLSC network equilibrium under the OLDSS as follows:

Determine $\left(Q^{1*}, Q^{2*}, Q^{3*}, Q^{4*}, \rho^*, \omega^*, \vartheta^*, \sigma^*, \delta^*\right) \in R_+^{M+MN+NOK+KM+K+2M+N+K}$, which satisfies:

$$\begin{aligned}
&\sum_{m=1}^{M}\left[\frac{\partial f_m\left(Q^{1*}\right)}{\partial q_m^{new}} - \omega_m^*\right] \times \left[q_m^{new} - q_m^{new*}\right] \\
&+\sum_{m=1}^{M}\sum_{n=1}^{N}\left[\frac{\partial c_{mn}\left(q_{mn}^*\right)}{\partial q_{mn}} + \frac{\partial c_n\left(Q^{2*}\right)}{\partial q_{mn}} + \omega_m^* + \alpha\vartheta_m^* - \sigma_n^*\right] \times \left[q_{mn} - q_{mn}^*\right] \\
&+\sum_{n=1}^{N}\sum_{o=1}^{O}\sum_{k=1}^{K}\left[r_{nok}^* + \frac{\partial c_{n,B}\left(\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K} q_{nok}^*, \theta\right)}{\partial q_{nok}} + \hat{c}_{nok}\left(q_{nok}^*\right) + \sigma_n^* - \rho_k^* - \delta_k^* - s_B\right] \times \left[q_{nok} - q_{nok}^*\right] \\
&+\sum_{k=1}^{K}\sum_{m=1}^{M}\left[\begin{array}{l}\dfrac{\partial c_{km}\left(q_{km}^*\right)}{\partial q_{km}} + \dfrac{\partial c_m\left(\sum\limits_{k=1}^{K} q_{km}^*\right)}{\partial q_{km}} + \dfrac{\partial \phi_m\left(\beta\sum\limits_{k=1}^{K} q_{km}^*\right)}{\partial q_{km}} + \eta(1-\beta) \\ + \dfrac{\partial c_{m,D}\left((1-\beta)\sum\limits_{k=1}^{K} q_{km}^*\right)}{\partial q_{km}} + \alpha_k\left(Q^{4*}\right) + \delta_k^* - \beta\omega_m^* - \vartheta_m^*\end{array}\right] \times \left[q_{km} - q_{km}^*\right] \\
&+\sum_{k=1}^{K}\left[\sum_{n=1}^{N}\sum_{o=1}^{O} q_{nok}^* - d_k\left(\rho_k^*\right)\right] \cdot \times \left[\rho_k - \rho_k^*\right] + \sum_{m=1}^{M}\left[q_m^{new*} + \beta\sum_{k=1}^{K} q_{km}^* - \sum_{n=1}^{N} q_{mn}^*\right] \times \left[\omega_m - \omega_m^*\right] \\
&+\sum_{m=1}^{M}\left[\sum_{k=1}^{K} q_{km}^* - \alpha\sum_{n=1}^{N} q_{mn}^*\right] \times \left[\vartheta_m - \vartheta_m^*\right] + \sum_{n=1}^{N}\left[\sum_{m=1}^{M} q_{mn}^* - \sum_{o=1}^{O}\sum_{k=1}^{K} q_{nok}^*\right] \times \left[\sigma_n - \sigma_n^*\right] \\
&+\sum_{k=1}^{K}\left[\sum_{n=1}^{N}\sum_{o=1}^{O} q_{nok}^* - \sum_{m=1}^{M} q_{km}^*\right] \times \left[\delta_k - \delta_k^*\right] \geq 0, \forall\left(Q^1, Q^2, Q^3, Q^4, \rho, \omega, \vartheta, \sigma, \delta\right) \in R_+^{M+MN+NOK+KM+K+2M+N+K}.
\end{aligned} \tag{15}$$

From VI (15), we obtain the E-CLSC network equilibrium under the OLDSS. Based on the equivalence of VI and CP [52], we obtain the endogenous price $\rho_{mn} = \frac{\partial c_{mn}\left(q_{mn}^*\right)}{\partial q_{mn}} + \omega_m^* + \alpha\vartheta_m^*$ from VI (4), $\rho_{nk} = r_{nok} + \frac{\partial c_{n,B}\left(\sum\limits_{o=1}^{O}\sum\limits_{k=1}^{K} q_{nok}*\right)}{\partial q_{nok}} - s_B + \sigma_n^*$ from VI (7), and $\frac{\partial c_o\left(r_{nok}^*\right)}{\partial r_{nok}} = q_{nok}^*$ and the logistics outsourcing price r_{nok}^* from VI (9). We also obtain $\rho_{km} = \alpha_k\left(Q^{4*}\right) +$

δ_k^* from VI (14). In addition, the overall profit of the network under the OLDSS is $\sum_{m=1}^{M} \pi_m + \sum_{n=1}^{N} \pi_n^{OL} + \sum_{o=1}^{O} \pi_o$.

6. Equilibrium of the E-CLSC under the SBLDSS

In this section, we consider the equilibrium of the E-CLSC network under the SBLDSS. (For example, JD (China), Suning (China), and Amazon (USA) have adopted the SBLDSS [3]). In Figure 1b, manufacturer $m\ (m = 1, \cdots, M)$ produces new products and sells them to e-retailer $n\ (n = 1, \cdots, N)$ with the transaction quantity equal to q_{mn} in one production cycle of the E-CLSC network under the SBLDSS; e-retailer $n\ (n = 1, \cdots, N)$ then sells these products directly to demand market $k\ (k = 1, \cdots, K)$ with the sales quantity equal to q_{nk}; and demand market $k\ (k = 1, \cdots, K)$ recycles these products and sends them to manufacturer $m\ (m = 1, \cdots, M)$ with the transaction quantity $q_{km} (k = 1, \cdots, K; m = 1, \cdots, M)$. Figure 3 shows the transaction diagram under the SBLDSS. For the manufacturers, their equilibrium decisions in the E-CLSC network under the SBLDSS are obtained in the same way as those in the E-CLSC network under the OLDSS, i.e., their equilibrium decisions under the SBLDSS also need to satisfy VI (4). However, the e-retailers use the SBLDSS to self-ship products to demand markets without the necessity to commission 3PLDPs for logistics distribution. In this model, SBLDSS cannot solve the problem of products being lost and damaged in the process of logistics distribution, and e-retailers still need to rely on the recording and traceability function of BT technology to supervise the logistics distribution process. Therefore, e-retailer n needs to pay $c_{n,B}\left(\sum_{k=1}^{K} q_{nk}, \theta\right)$ for the BT investment in one production cycle under the SBLDSS. To encourage the application and development of new technologies, the government provides a BT subsidy s_B for each product item sold by e-retailers, with the total amount of subsidy equal to $s_B \sum_{k=1}^{K} q_{nk}$.

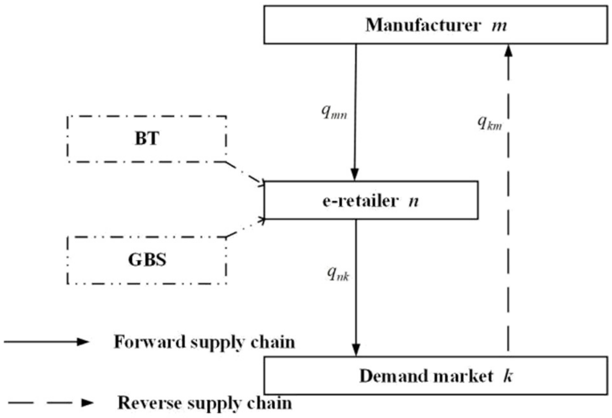


Figure 3. Transaction diagram under the SBLDSS.

6.1. E-Retailers' Equilibrium Decisions under the SBLDSS

N competing e-retailers obtain products from M manufacturers and sell and distribute products directly to K demand markets under the SBLDSS. Hence, e-retailer $n\ (n = 1, \cdots, N)$ needs to decide on the products purchased from manufacturer $m\ (m = 1, \cdots, M)$, q_{mn}, and sell them directly to demand market $k\ (k = 1, \cdots, K)$ with the transaction quantity equal to q_{nk} in one production cycle. Thus, the income of e-retailer $n\ (n = 1, \cdots, N)$ in one production cycle includes its revenue $\sum_{k=1}^{K} \rho_{nk} q_{nk}$ (ρ_{nk} is the endogenous retail price) and the government's subsidy $s_B \sum_{k=1}^{K} q_{nk}$, and its cost includes the product cost $\sum_{m=1}^{M} \rho_{mn} q_{mn}$ (ρ_{mn} is the endogenous wholesale price), the product display sales cost $c_n\left(Q^2\right)$, the logistics distribution cost $\overline{c}_n\left(\sum\limits_{k=1}^{K} q_{nk}\right)$, and the BT investment cost $c_{n,B}\left(\sum\limits_{k=1}^{K} q_{nk}, \theta\right)$. Let the net profit of e-retailer $n(n = 1, \cdots, N)$ in one production cycle under the SBLDSS be π_n^{SL}. Then, the maximization problem of e-retailer n in this model is:

$$\max \pi_n^{SL} = \sum_{k=1}^{K} \rho_{nk} q_{nk} + s_B \sum_{k=1}^{K} q_{nk} - \sum_{m=1}^{M} \rho_{mn} q_{mn} - c_n\left(Q^2\right) - \overline{c}_n\left(\sum_{k=1}^{K} q_{nk}\right) - c_{n,B}\left(\sum_{k=1}^{K} q_{nk}, \theta\right) \tag{16}$$

$$\begin{gathered} \text{s.t.} \sum_{k=1}^{K} q_{nk} \leq \sum_{m=1}^{M} q_{mn} \\ q_{mn}, q_{nk} \geq 0, \forall m, k \end{gathered} \tag{17}$$

Constraint (17) indicates that the total quantity of products sold by e-retailer n does not exceed its purchase quantity.

Proposition 4. *In view of Assumption 7, the profit of e-retailer n under the SBLDSS, π_n^{SL}, is a concave function of q_{mn} and q_{nk}.*

Proof. The proof is the same as Proposition 2. ☐

Theorem 5. In view of Assumption 3, the equilibrium decisions of N *e-retailers under the SBLDSS are obtained by solving the following VI [18]:*

Determine $\left(Q^{2*}, Q^{5*}, \lambda^*\right) \in R_+^{MN+NK+N}$, *which satisfies:*

$$\begin{aligned} &\sum_{m=1}^{M} \sum_{n=1}^{N} \left[\rho_{mn}^* + \frac{\partial c_n\left(Q^{2*}\right)}{\partial q_{mn}} - \lambda_n^*\right] \times \left[q_{mn} - q_{mn}^*\right] + \sum_{n=1}^{N} \sum_{k=1}^{K} \left[\frac{\partial \overline{c}_n\left(\sum\limits_{k=1}^{K} q_{nk}^*\right)}{\partial q_{nk}} + \frac{\partial c_{n,B}\left(\sum\limits_{k=1}^{K} q_{nk}^*, \theta\right)}{\partial q_{nk}} + \lambda_n^* - \rho_{nk}^* - s_B\right] \times \left[q_{nk} - q_{nk}^*\right] \\ &+ \sum_{n=1}^{N} \left[\sum_{m=1}^{M} q_{mn}^* - \sum_{k=1}^{K} q_{nk}^*\right] \times \left[\lambda_n - \lambda_n^*\right] \geq 0, \forall \left(Q^2, Q^5, \lambda\right) \in R_+^{MN+NK+N}, \end{aligned} \tag{18}$$

where λ_n is the Lagrange multiplier of (17).

Proof. The proof is the same as that of Theorem 1. ☐

Property 2. *In view of Assumptions 5–7, the decision variables of e-retailer n under the SBLDSS, q_{mn} and q_{nk}, are decreasing functions of the BT input cost θ, and are increasing functions of the GBS quota s_B.*

Proof. The proof is the same as that of Property 1. ☐

The interpretation of Property 2 from the economic point of view is the same as that of Property 1.

6.2. Demand Markets' Equilibrium Decisions under the SBLDSS

The activities of demand market k $(k = 1, \cdots, K)$ under the SBLDSS are the same as those that occur under the OLDSS. Thus, for demand market k $(k = 1, \cdots, K)$, its equilibrium decisions under the SBLDSS model can be represented by VI (19) given below, which is similar to that of VI (14) given for the equilibrium decisions under the OLDSS. VI (19) can be stated as follows:

Determine $\left(Q^{5*}, Q^{4*}, \rho^*, \mu^*\right) \in R_{+}^{NK+KM+2N}$ which satisfies:

$$\begin{aligned}
&\sum_{n=1}^{N}\sum_{k=1}^{K}\left[\rho_{nk}^{*} + \hat{c}_{nk}\left(q_{nk}^{*}\right) - \mu_k^{*} - \rho_k^{*}\right] \times \left[q_{nk} - q_{nk}^{*}\right] \\
&+ \sum_{k=1}^{K}\sum_{m=1}^{M}\left[\alpha_k\left(Q^{4*}\right) + \mu_k^{*} - \rho_{km}^{*}\right] \times \left[q_{km} - q_{km}^{*}\right] \\
&+ \sum_{k=1}^{K}\left[\sum_{n=1}^{N} q_{nk}^{*} - d_k\left(\rho_k^{*}\right)\right] \times \left[\rho_k - \rho_k^{*}\right] \\
&+ \sum_{k=1}^{K}\left[\sum_{n=1}^{N} q_{nk}^{*} - \sum_{m=1}^{M} q_{km}^{*}\right] \times \left[\mu_k - \mu_k^{*}\right] \geq 0, \forall\left(Q^5, Q^4, \rho, \mu\right) \in R_{+}^{NK+KM+2N}.
\end{aligned} \tag{19}$$

6.3. E-CLSC Network Equilibrium Decisions under the SBLDSS

When all manufacturers, all e-retailers, and all demand markets arrive at equilibrium, then VI (4), VI (18), and VI (19) will be satisfied simultaneously, which implies that the E-CLSC network has arrived at equilibrium. By adding VI (4), VI (18), and VI (19) and deleting the endogenous prices, we obtain the E-CLSC network equilibrium under the SBLDSS as follows:

Determine $\left(Q^{1*}, Q^{2*}, Q^{5*}, Q^{4*}, \rho^*, \omega^*, \vartheta^*, \lambda^*, \mu^*\right) \in R_{+}^{M+MN+NK+KM+K+2M+N+K}$, which satisfies:

$$\begin{aligned}
&\sum_{m=1}^{M}\left[\frac{\partial f_m\left(Q^{1*}\right)}{\partial q_m^{new}} - \omega_m^{*}\right] \times \left[q_m^{new} - q_m^{new*}\right] \\
&+ \sum_{m=1}^{M}\sum_{n=1}^{N}\left[\frac{\partial c_{mn}\left(q_{mn}^{*}\right)}{\partial q_{mn}} + \frac{\partial c_n\left(Q^{2*}\right)}{\partial q_{mn}} + \omega_m^{*} + \alpha\vartheta_m^{*} - \lambda_n^{*}\right] \times \left[q_{mn} - q_{mn}^{*}\right] \\
&+ \sum_{n=1}^{N}\sum_{k=1}^{K}\left[\frac{\partial \bar{c}_n\left(\sum\limits_{k=1}^{K} q_{nk}^{*}\right)}{\partial q_{nk}} + \frac{\partial c_{n,B}\left(\sum\limits_{k=1}^{K} q_{nk}^{*}, \theta\right)}{\partial q_{nk}} + \hat{c}_{nk}\left(q_{nk}^{*}\right) + \lambda_n^{*} - \mu_k^{*} - \rho_k^{*} - s_B\right] \times \left[q_{nk} - q_{nk}^{*}\right] \\
&+ \sum_{k=1}^{K}\sum_{m=1}^{M}\left[\begin{array}{l}
\dfrac{\partial c_{km}\left(q_{km}^{*}\right)}{\partial q_{km}} + \dfrac{\partial c_m\left(\sum\limits_{k=1}^{K} q_{km}^{*}\right)}{\partial q_{km}} + \dfrac{\partial \phi_m\left(\beta\sum\limits_{k=1}^{K} q_{km}^{*}\right)}{\partial q_{km}} + \eta(1-\beta) \\
+ \dfrac{\partial c_{m,D}\left((1-\beta)\sum\limits_{k=1}^{K} q_{km}^{*}\right)}{\partial q_{km}} + \alpha_k\left(Q^{4*}\right) + \mu_k^{*} - \beta\omega_m^{*} - \vartheta_m^{*}
\end{array}\right] \times \left[q_{km} - q_{km}^{*}\right] \\
&+ \sum_{k=1}^{K}\left[\sum_{n=1}^{N} q_{nk}^{*} - d_k\left(\rho_k^{*}\right)\right] \times \left[\rho_k - \rho_k^{*}\right] + \sum_{m=1}^{M}\left[q_m^{new*} + \beta\sum_{k=1}^{K} q_{km}^{*} - \sum_{n=1}^{N} q_{mn}^{*}\right] \times \left[\omega_m - \omega_m^{*}\right] \\
&+ \sum_{m=1}^{M}\left[\sum_{k=1}^{K} q_{km}^{*} - \alpha\sum_{n=1}^{N} q_{mn}^{*}\right] \times \left[\vartheta_m - \vartheta_m^{*}\right] + \sum_{n=1}^{N}\left[\sum_{m=1}^{M} q_{mn}^{*} - \sum_{k=1}^{K} q_{nk}^{*}\right] \times \left[\lambda_n - \lambda_n^{*}\right] \\
&+ \sum_{k=1}^{K}\left[\sum_{n=1}^{N} q_{nk}^{*} - \sum_{m=1}^{M} q_{km}^{*}\right] \times \left[\mu_k - \mu_k^{*}\right] \geq 0, \forall\left(Q^1, Q^2, Q^5, Q^4, \rho, \omega, \vartheta, \lambda, \mu\right) \in R_{+}^{M+MN+NK+KM+K+2M+N+K}.
\end{aligned} \tag{20}$$

From VI (20), we obtain the E-CLSC network equilibrium under the SBLDSS. Based on the equivalence of VI and CP [52], we obtain the endogenous price $\rho_{mn} = \frac{\partial c_{mn}\left(q_{mn}^{*}\right)}{\partial q_{mn}} + \omega_m^{*} + \alpha\vartheta_m^{*}$ from VI (4), $\rho_{nk} = \dfrac{\partial c_n\left(\sum\limits_{k=1}^{K} q_{nk}\right)}{\partial q_{nk}} + \dfrac{\partial c_{n,B}\left(\sum\limits_{k=1}^{K} q_{nk}, \theta\right)}{\partial q_{nk}} - s_B + \lambda_n$ from VI (18), and $\rho_{km} = \alpha_k\left(Q^{4*}\right) + \mu_k^{*}$ from VI (19). In addition, the E-CLSC profit under the SBLDSS is $\sum\limits_{m=1}^{M} \pi_m + \sum\limits_{n=1}^{N} \pi_n^{SL}$.

7. Numerical Analysis

In this section, by solving a numerical example, we verify all the theorems and all the properties in Sections 5 and 6 and analyze the impacts of the BT input cost and the

GBS quota on the equilibrium decisions. Moreover, by comparing the profits of the e-retailers under two LDS strategies, we obtain the best LDS strategy for the e-retailers, which provides a scientific basis for the LDS decision making of the e-retailers.

In this numerical example, we use the same CLSC network as that used in [26], with $M,\ N,\ O,\ K = 2$ ($M,\ N,\ O$ and K are the numbers of manufacturers, e-retailers, 3PLDPs, and demand markets, respectively) in the network and use the same cost functions as those used in [30], where all the cost functions satisfy Assumptions 4–7. The cost functions can be described as follows:

Under the OLDSS:

Manufacturers:

$$f_m(Q^1) = 2.5(q_m^{new})^2 + q_1^{new}q_2^{new} + 2q_m^{new}$$
$$\varphi_m\left(\beta\sum_{k=1}^{K} q_{km}\right) = \left(\beta\sum_{k=1}^{K} q_{km}\right)^2 + \beta\sum_{k=1}^{K} q_{km}$$
$$c_{km}(q_{km}) = q_{km} + 5$$
$$c_m\left(\sum_{k=1}^{K} q_{km}\right) = 1.8\sum_{k=1}^{K} q_{km} + 3$$
$$c_{m,D}\left(\bar{\beta}\sum_{k=1}^{K} q_{km}\right) = 0.5\left(\bar{\beta}\sum_{k=1}^{K} q_{km}\right)^2 + 3.5\left(\bar{\beta}\sum_{k=1}^{K} q_{km}\right)$$
$$c_{mn}(q_{mn}) = 0.1q_{mn}^2 + q_{mn}$$

E-retailers:

$$c_n(Q^2) = 0.5\left(\sum_{m=1}^{M} q_{mn}\right)^2$$
$$c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K} q_{nok}, \theta\right) = \theta^2\left(\sum_{o=1}^{O}\sum_{k=1}^{K} q_{nok}\right)^2$$

3PLDPs:

$$c_{nok}(r_{nok}) = 25r_{nok}^2$$

Demand markets:

$$\hat{c}_{nok}(q_{nok}) = q_{nok} + 5$$
$$\alpha_k(Q^5) = 0.5\left(\sum_{m=1}^{M} q_{km}\right)^2$$
$$d_1 = -3\rho_1 - \rho_2 + 6000,$$
$$d_2 = -3\rho_2 - \rho_1 + 6000.$$

Under the SBLDSS:

E-retailers:

$$\bar{c}_n\left(\sum_{k=1}^{K} q_{nk}\right) = 0.03\left(\sum_{k=1}^{K} q_{nk}\right)^2 + 0.01\left(\sum_{k=1}^{K} q_{nk}\right)$$
$$c_{n,B}\left(\sum_{k=1}^{K} q_{nk}, \theta\right) = \theta^2\left(\sum_{k=1}^{K} q_{nk}\right)^2$$

Demand markets:

$$\hat{c}_{nk}(q_{nk}) = q_{nk} + 5$$

We apply the modified projection algorithm [53] by Matlab (2012) to solve VI (15) and VI (20), respectively, using an iteration step of 0.01 and a termination error of 10^{-4} in this algorithm. The processor we used is the Core i5 (Lenovo, Xiaoxin), with an average runtime of 150 s. By solving Equations (1), (5) and (8), respectively, in conjunction with VI (15), we obtain π_m, π_n^{OL}, and π_o, respectively, at equilibrium under the OLDSS. On the other hand, by solving Equations (1) and (16), respectively, in conjunction with VI (20), we obtain π_m and π_n^{SL} at equilibrium under the SBLDSS. (Note that, in one production cycle of the OLDSS, e-retailer n sells $\sum_{o=1}^{O} q_{nok}$ items of its products by delivering them to demand market k via 3PLDPs.)

7.1. Impact of the BT Input Cost on the Selection of the Two LDS Strategies

In order to analyze the impact of the e-retailers' BT input cost, θ, on their selection of the optimal LDS strategy, we set the GBS quota θ equal to 0 According to [45], we set the initial and the final values of the e-retailers' BT input cost parameter θ equal to 0 and 1, respectively, with the changes in θ equal to 0.1 in each step. According to [30], we set the parameters $\alpha = 0.5$, $\beta = 0.8$, $\eta = 2$. We solve VI (15) and VI (20), respectively, to obtain the equilibrium of the E-CLSC under both the OLDSS and the SBLDSS corresponding to different values of θ. The equilibriums under these two LDS strategies corresponding to different values of θ are shown in Figure 4a–e, with their corresponding profits shown in Figure 4f–h. By comparing the e-retailers' profits under these two LDS strategies corresponding to different values of θ, we obtain the impact of the e-retailers' BT input costs on their selections of the optimal LDS strategy (see Figure 5).

(1) From Figure 4a,b, for both LDS strategies, when the e-retailers' BT input cost θ increases, e-retailers, as rational decision makers, will reduce the purchase and sales quantities of products to avoid losses of profits. Thus, these numerical results are consistent with Property 1 and Property 2 in Sections 5 and 6. From Figure 4c,d, for both LDS strategies, when the e-retailers' BT input costs increase, manufacturers will reduce the quantity of production of new products and the number of used products collected from demand markets due to the decline in sales. From Figure 4e, the selling price in the demand market is an increasing function of e-retailers' BT input costs because, when the sales quantity of the production decreases, the supply of goods will decrease and the selling price will increase due to a shortage of products.

(2) From Figure 4f,g, when the e-retailers' BT input costs increase, the profits of manufacturers and 3PLDPs will decrease due to the decrease in sales quantities.

(3) From Figure 4h, retailers' BT input costs have a positive impact on their profitability. More precisely, when the retailers' BT input costs increase, although their sales quantities decrease, their benefits increase because the benefits caused by the increase in product prices are much greater than the losses caused by the decrease in sales quantities. Thus, the profits of the e-retailers are positively correlated with their BT input costs. Moreover, e-retailers, as rational decision makers, will choose the best LDS strategy corresponding to different BT input costs. When the e-retailers' BT input cost is low (less than 0.7), e-retailers will obtain more profits by choosing the SBLDSS retailers. When the e-retailers' BT input cost is high (higher than 0.7), e-retailers will obtain more profits by choosing the OLDSS (see Figure 5).

E-retailers invest in BT to supervise the logistics distribution process of the products they sell and to ensure the safety of the logistics distribution process of the products. As the e-retailers' BT input cost increase, reducing sales and increasing e-retailers' profits are conducive to saving resources, but are causing damages to the profits of the manufacturers and 3PLDPs. Comparing the profits of e-retailers under the two LDS strategies, when the BT input cost is low, e-retailers can obtain higher profits by choosing the SBLDSS, and when the BT input cost is high, OLDSS is the best LDS strategy for the e-retailers, which is consistent with Dong et al.'s conclusion that e-retailers under SBLDSS are profitable when blockchain cost is low [36]. Among the two LDS strategies, manufacturers are more profitable under the OLDSS than the SBLDSS, and 3PLDPs are only profitable under the OLDSS. Moreover, e-retailers can sell more products under the OLDSS than under the SBLDSS, and the product price is also lower under the OLDSS. As a result, e-retailers' OLDSS is more conducive to meeting market needs and provides more benefits to all the members of the E-CLSC network.

As shown in Figure 5, e-retailers choose different LDS strategies corresponding to different BT input costs. In the next two sections, Sections 7.2 and 7.3, we shall discuss the impact of the GBS quota under low BT input cost and high BT input cost, respectively.

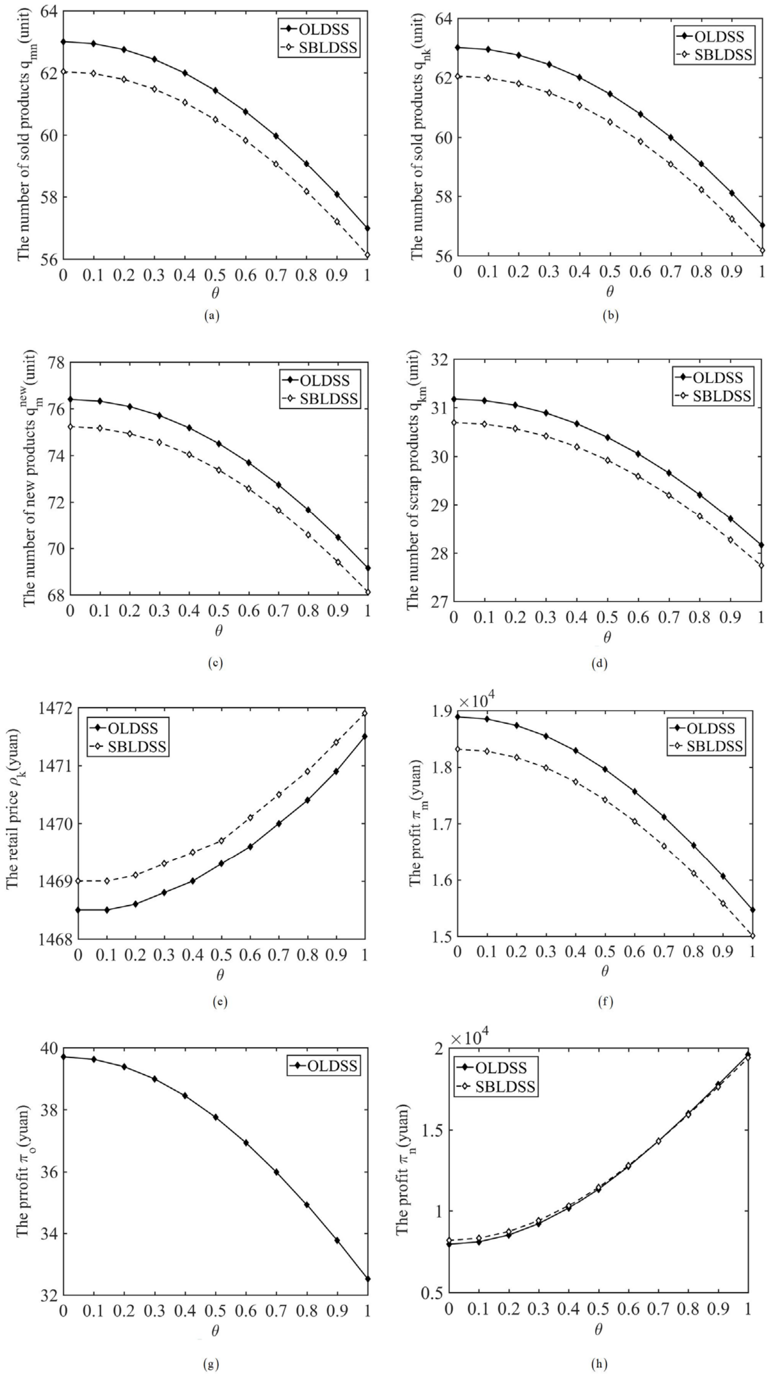


Figure 4. The effect of the BT input cost on the decision variables and the profits. (**a**) Changes of q_{mn}; (**b**) Changes of q_{nk}; (**c**) Changes of q_m^{new}; (**d**) Changes of q_{km}; (**e**) Changes of ρ_k; (**f**) Changes of π_m; (**g**) Changes of π_o; (**h**) Changes of π_n.

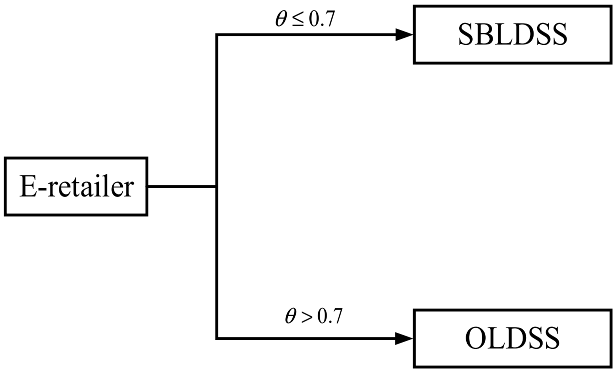


Figure 5. The effect of the blockchain technology level under e-retailers' different LDS strategies.

7.2. Impact of the GBS Quota When the BT Input Cost Is Low

In this section, we analyze the impact of the GBS quota on the decision making and profits at equilibrium when the BT input cost θ is low (i.e., we set $\theta = 0.3$). According to [31], we set the initial and final values of the GBS quota as equal to 0 and 100, respectively, with the change in the GSB quota equal to 10 in each step, and we set the other parameters to have the same values as those given in Section 6.1. We solve VI (15) and VI (20) to obtain the equilibrium decisions (see Figure 6a–c) and the profits (see Figure 6f–h) under both the OLDSS and the SBLDSS. By comparing the e-retailers' profits under the two LDS strategies, we obtain the impact of the GBS quota on the optimal LDS strategy of the e-retailers when the BT input cost is low.

(1) From Figure 6a,b, the quantity of the purchased products and the quantity of the sale products are positively correlated with the GBS quota. Thus, these numerical results are consistent with Property 1 and Property 2 in Sections 4 and 5. When the GBS quota is increased by the government, the e-retailers will obtain more funding; thus, the e-retailers will increase the quantity of the purchased products, and hence, their sales quantity will increase. From Figure 6c,d, when the government increases the GBS quota, the manufacturers will increase the production of new products to increase their profits. Due to the increase in product sales, the quantity of used products recycled by manufacturers will also increase. From Figure 6e, the selling price of the product is negatively correlated with the GBS quota. As the supply of products increases with the increase in the GBS, the price of the products will be decreased.

(2) From Figure 6f,g, when the GBS quota increases, the sales of products will increase; hence, the profits of the manufacturers and the 3PLDPs will also increase. From Figure 4f,g, when the e-retailers' BT input costs increase, the profits of the manufacturers and the 3PLDPs should decrease; however, due to the implementation of subsidies by the government, the loss of profits due to the increase in e-retailers' BT input costs is compensated, and hence, the profits of the manufacturers and the 3PLDPs increase, which promotes the overall development of E-CLSC. Therefore, the government must implement subsidies for the e-retailers' BT.

(3) From Figure 6h, e-retailers' profits are positively correlated with the GBS quota, which is consistent with the literature [16]. The increase in the GBS quota and the decrease in the selling price of the products have negative impacts on the profits of e-retailers, but the increase in sales quantities will cause an increase in the profits of e-retailers. Thus, the gain from the increase in sales will outweigh the loss from the decrease in the selling price; hence, the profits of the e-retailers will increase.

(4) From Figure 6h, when the e-retailers' BT input costs are low, they will choose the SBLDSS as their optimal LDS strategy. Thus, this numerical result is consistent with the conclusion obtained from Figure 5. When the government subsidy increases, the production and sales quantities will increase, and the profit of e-retailers will also increase; however, the impacts on the growth rates of the profits of the e-retailers under both LDS strategies

are the same. Therefore, the GBS quota has no significant effect on the selection of the optimal LDS strategy for the e-retailers.

In conclusion, when the e-retailers' input cost θ is low, the government's subsidy for BT e-retailers' BT will stimulate the purchases and sales of e-retailers' products, which will increase the profits of the e-retailers. When the GBS quota increases, the negative impact of the BT investment on the profits of the manufacturers and the 3PLDPs will decrease; thus, the profits of the manufacturers and the 3PLDPs will increase. Thus, GBS has played a key role in promoting the overall development of E-CLSC via expanding the market demands. However, the growth rates of the profits of the e-retailers under both LDS strategies are the same; thus, the GBS quota does not change the optimal LDS strategy for the e-retailers.

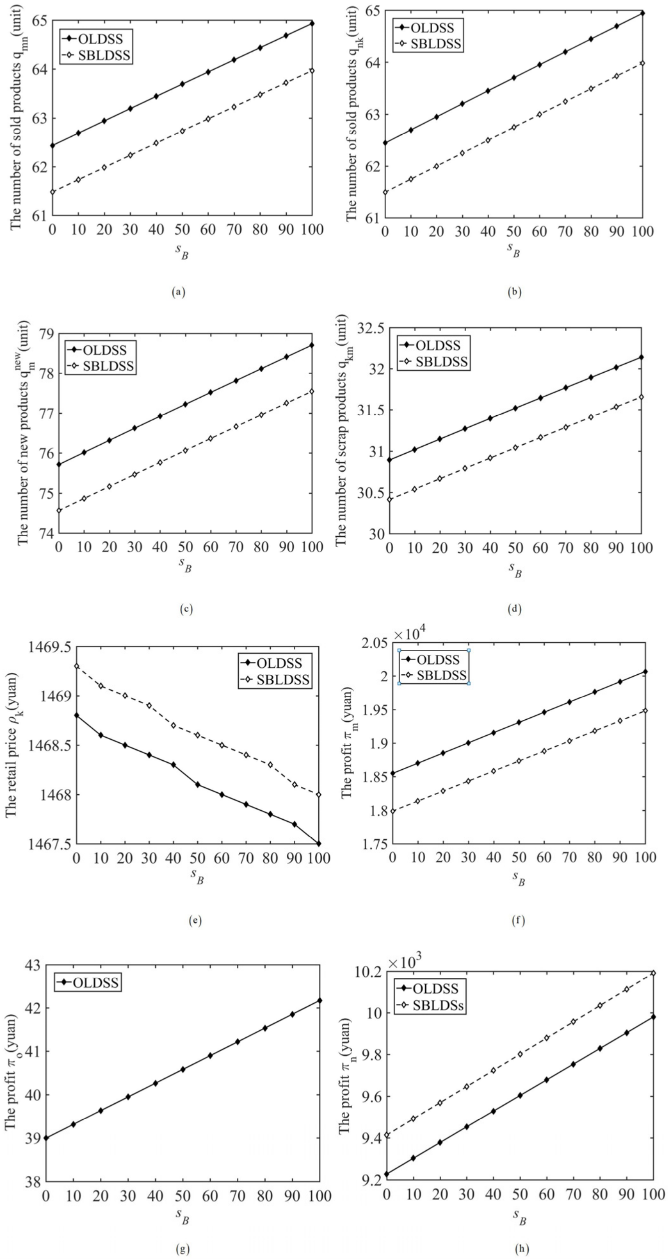


Figure 6. The effect of the GBS quota on the decision variables and the profits when the BT input cost is low. (**a**) Changes of q_{mn}; (**b**) Changes of q_{nk}; (**c**) Changes of q_m^{new}; (**d**) Changes of q_{km}; (**e**) Changes of ρ_k; (**f**) Changes of π_m; (**g**) Changes of π_o; (**h**) Changes of π_n.

7.3. Impact of the GBS Quota when the BT Input Cost Is High

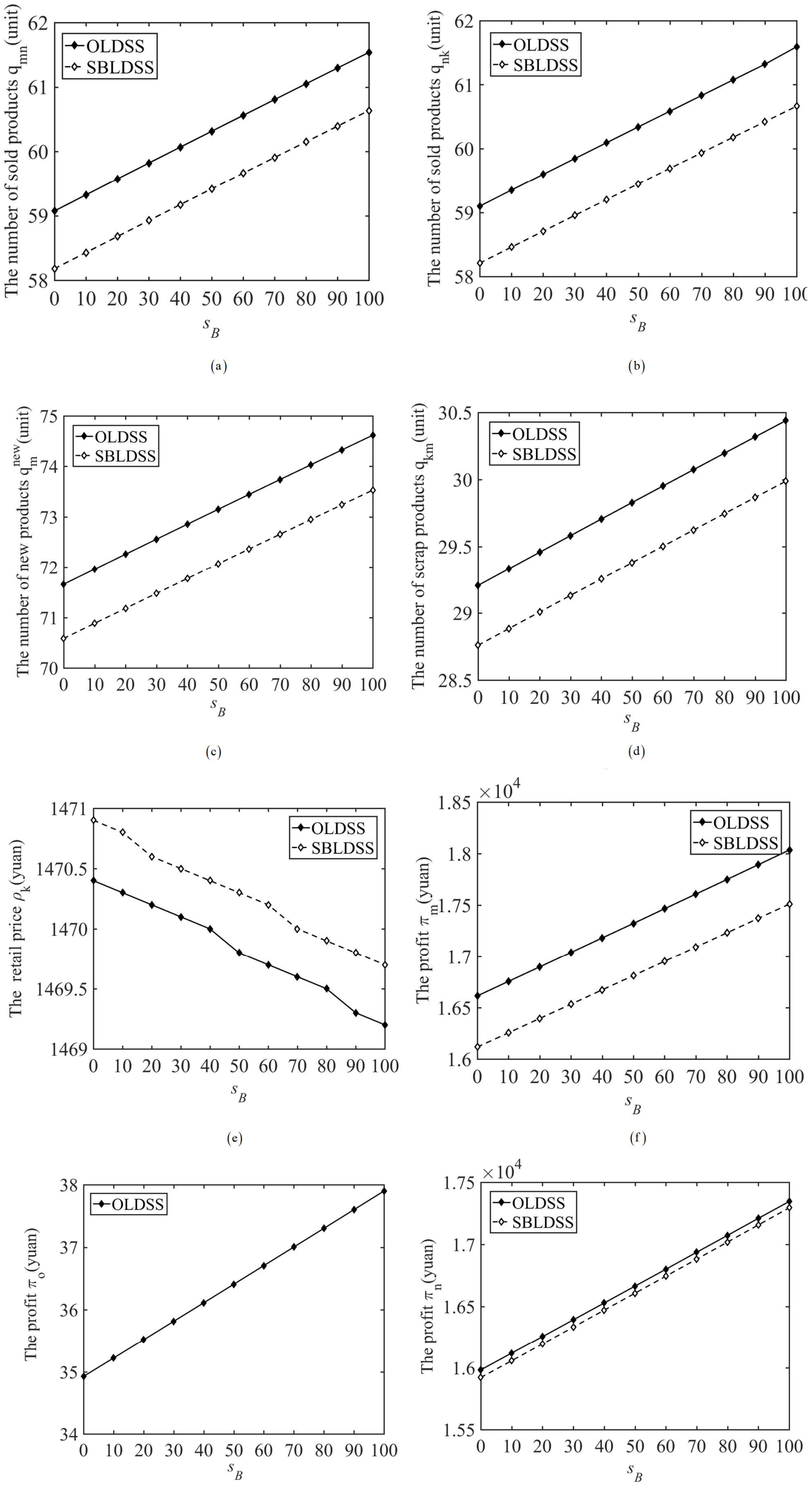
In this section, we analyze the impact of the GBS quota on decision making and the profits at equilibrium when the BT input cost θ is high (i.e., we set $\theta = 0.8$). According to [31], we set the values of the GBS quota s_B and the other parameters as the same as those set in Section 7.2. We solve VI (15) and VI (20) to obtain the equilibrium decisions (see Figure 7a–e) and the profits (see Figure 7f–h) under both the OLDSS and the SBLDSS. By comparing the e-retailers' profits under the two LDS strategies, we obtain the impact of the GBS quota on the optimal LDS strategy of the e-retailers when the BT input cost is high.

(1) From Figure 7a,b, the quantity of the purchased products and the quantity of the sale products are positively correlated with the GBS quota. As the GBS quota increases, e-retailers will take the initiative to increase the quantity of the purchased products and the quantity of the sale products. Thus, these numerical results are consistent with Property 1 and Property 2 in Sections 5 and 6. From Figure 7c,d, the production quantity of the manufacturers and the quantity of used products recycled by demand markets, which are affected by the purchase quantity and the sales quantity of the retailers, are positively correlated with the GBS quota. From Figure 7e, the selling price of the product is negatively correlated with the GBS quota.

(2) From Figure 7f,g, when the GBS quota increases, the profits of the manufacturers and the 3PLDPs will also increase. From Figure 4f,g, when the e-retailers' input costs increase, the profit of manufacturers and the profit of 3PLDPs should decrease, but due to the implementation of subsidies by the government, the loss of profits due to the increase in e-retailers' BT input cost is compensated; hence, the profits of the manufacturers and the 3PLDPs increase, which promotes the overall development of E-CLSC. Therefore, the government must implement subsidies for e-retailers' BT input.

(3) From Figure 7h, the profit of the e-retailers is positively correlated with the GBS quota [16]. When the GBS quota increases, the gain from the increase in sales of the retailers will outweigh the loss from the decrease in the selling price of the retailers; thus, the profit of the e-retailers will increase. When the e-retailers' BT input costs are high, they will choose the OLDSS as their optimal LDS strategy. Thus, this numerical result is consistent with the conclusion obtained from Figure 5. Under the influence of the GBS quota, sales quantities play a crucial role in the profits of e-retailers, who determine the optimal LDS strategy based on their own profit. When the government subsidy increases, the impacts on the growth rates of the profits of the e-retailers under both LDS strategies are the same. Therefore, the GBS quota does not directly affect the selection of the optimal LDS strategy for the e-retailers.

In conclusion, when the e-retailers' BT input cost θ is high, the government's subsidy for e-retailers' BT investment not only expands the market demand for products, but also increases the profits of the manufacturers, the 3PLDPs, and the e-retailers. Thus, the government's subsidy is beneficial to the overall development of E-CLSC. On the one hand, the GBS will increase the motivation of the e-retailers to invest in BT. On the other hand, since the growth rates of the profit of the e-retailers under the two LDS strategies are the same, the GBS quota does not directly affect the selection of the LDS strategies for the e-retailers.



(a) (b)

(c) (d)

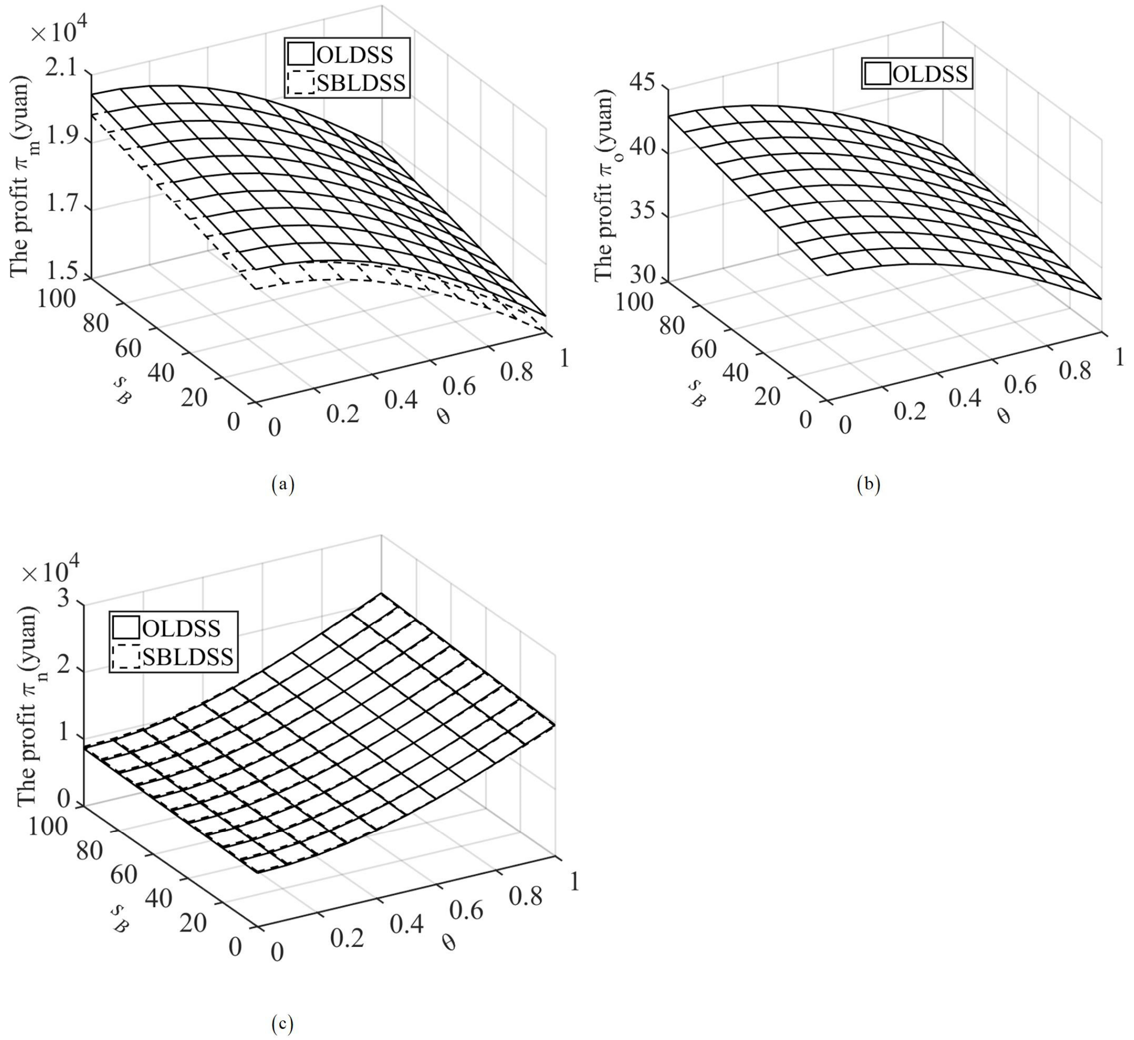
(e) (f)

(g) (h)

Figure 7. The effect of the GBS quota on the decision variables and the profits when the BT input cost is high. (**a**) Changes of q_{mn}; (**b**) Changes of q_{nk}; (**c**) Changes of q_m^{new}; (**d**) Changes of q_{km}; (**e**) Changes of ρ_k; (**f**) Changes of π_m; (**g**) Changes of π_o; (**h**) Changes of π_n.

7.4. The Combined Impact of E-Retailers' BT Input Costs and the GBS Quota

In Section 7.1, we analyzed the impact of e-retailers' BT input costs on equilibrium decisions and the selection of the optimal LDS strategy for the e-retailers. In Sections 7.2 and 7.3, we analyzed the impact of the GBS quota on the equilibrium decisions and the selection of the optimal LDS strategy for e-retailers under the conditions that the e-retailers have low and high BT input costs, respectively. Thus, we have already verified Property 1 and Property 2 given in Sections 5 and 6, which concern, respectively, the impact of the e-retailers' BT input costs and that of the GBS quota on the equilibrium decisions. Hence, in this section, we shall analyze the combined impact of these two parameters on the profits of each E-CLSC member. The results of this analysis are given in Figure 8a–c. In these figures, we put the e-retailers' input BT cost θ on the x-axis, according to [45]; we set the initial and the final values of θ equal to 0 and 1, respectively, with the step-size equal to 0.1, and put the values of the GBS quota s_B on the y-axis, according to [33]; and we set the initial and the final values of s_B as equal to 0 and 100, respectively, with the step-size equal to 10. By setting the values of the other parameters as the same as those in Section 7.1, we obtain the changes in profits of each E-CLSC member with respect to the changes in θ and s_B.



(a) (b) (c)

Figure 8. The effect of BT input cost and GBS quota. (**a**) Changes of π_m; (**b**) Changes of π_o; (**c**) Changes of π_n.

(1) From Figure 8a, when the e-retailers' BT input costs increase, the profits of the manufacturers under both the OLDSS and the SBLDSS decrease. The above results are the same as those obtained from Figure 4f. Moreover, also from Figure 8a, when the GBS

quota increases, the profits of the manufacturers under both the OLDSS and the SBLDSS increase. The above results are the same as those obtained from Figures 6f and 7f. For both LDS strategies, the positive impact on the manufacturers' profits due to the increase in the GBS quota can easily offset the negative impact due to the increase in the e-retailers' BT input costs. Comparing the profits of the manufacturers under the two LDS strategies, we find that, under the combined impact of the two parameters, manufacturers obtain a larger profit under the OLDSS.

(2) From Figure 8b, when the BT input cost increases, the profit of the 3PLDPs under the OLDSS decreases. The above result is the same as that obtained from Figure 4g. Moreover, also from Figure 8b, when the GBS quota increases, the profit of the 3PLDPs under the OLDSS increases. The above result is the same as those obtained from Figures 6f and 7f. However, 3PLDPs can only be profitable under the OLDSS. The positive impact on the 3PLDPs' profits due to the increase in the GBS quota can easily offset the negative impact due to the increase in the e-retailers' BT input costs.

(3) From Figure 8c, when the BT input cost increases, the profits of the e-retailers under both the OLDSS and the SBLDSS increase. The above result is the same as that obtained from Figure 4h. Therefore, the e-retailers must increase the BT input cost to increase their profits. Moreover, also from Figure 8c, when the GBS quota increases, the profits of the e-retailers under both the OLDSS and the SBLDSS increase [16]. The above results are the same as those given in Figures 6h and 7h. From Figure 8c, it can also be seen that e-retailers, as rational decision makers, select the best LDS strategy that provides them with higher profits. When the BT input cost is low, e-retailers choose the SBLDSS as the best LDS strategy, and when the BT input cost is high, e-retailers choose the OLDSS as the best LDS strategy. The above results are the same as those obtained from Figure 5. In addition, other literature has also found that e-retailers choose SBLDSS to obtain higher profits when the blockchain cost is low [36].

(4) From Figure 8a–c, when the input cost of BT increases, the profits of both the manufacturers and the 3PLDPs decrease. However, if the government implements a subsidy for each item sold by e-retailers, the positive impact on their profits due to the subsidy of the government will reduce the negative impact due to the BT input cost; hence, the profits of manufacturers and 3PLDPs will increase. Thus, the GBS quota must be implemented to improve the overall profit of E-CLSC.

In conclusion, when the BT input cost increases, the selling prices of the products also increase, which provides the e-retailers with more profits. However, the BT input cost can decrease the profits of other E-CLSC members. Thus, by subsidizing the e-retailers' BT investments, the GBS can help them to increase their product sales and profits and indirectly help the manufacturers and the 3PLDPs to increase their profits; in this way, the imbalance in profits between all members of the E-CLSC network will be reduced. While the BT input cost plays a key role in e-retailers' selection of the optimal LDS strategy, the GBS regulates the transaction quantities of products in the markets, helps the demand markets to meet their demands, and improves the social welfare; thus, the GBS is beneficial in terms of helping the overall development of the E-CLSC and satisfying the needs of customers. As far as the combined impact of the BT input cost and the GBS quota on the profits of all the members of the E-CLSC are concerned, the OLDSS is the best choice for the e-retailers.

The impacts of the blockchain input cost (θ) and GBS quota (s_B) on the decision variables and the profits are shown in Tables 5 and 6.

Table 5. The impact of the blockchain input cost and GBS quota under the OLDSS.

	q_{mn}	q_{nk}	q_m^{new}	q_{km}	ρ_k	π_m	π_o	π_n
θ	↓	↓	↓	↓	↑	↓	↓	↑
s_B	↑	↑	↑	↑	↓	↑	↑	↑

In the tables, ↑ means increase; ↓ means decrease.

Table 6. The impact of the blockchain input cost and GBS quota under the SBLDSS.

	q_{mn}	q_{nk}	q_m^{new}	q_{km}	ρ_k	π_m	π_n
θ	↓	↓	↓	↓	↑	↓	↑
s_B	↑	↑	↑	↑	↓	↑	↑

In the tables, ↑ means increase; ↓ means decrease.

8. Conclusions

In this paper, we study the E-CLSC network equilibrium problem considering the e-retailers' BT input costs and the GBS quota under the OLDSS and the SBLDSS. Moreover, we also analyze how the BT input cost and the GBS quota can affect the optimal selection of the LDS strategy for e-retailers. The results are as follows:

(1) Under the two LDS strategies, the production and transaction of the new products and the recycled products are negatively correlated with e-retailers' BT input costs. From the market perspective, this implies that the increase in the retailers' BT input costs inhibits the market trading of products and hinders market development. Thus, when the retailers' BT input costs increase, the negative impact of the retailers' BT input cost becomes more prominent. Under the two LDS strategies, the retailers' BT input costs have a positive impact on the profit of e-retailers and a negative impact on the profits of the manufacturers and the 3PLDPs. Comparing the profits of the e-retailers under the two LDS strategies, it is found that when the retailers' BT costs are low, e-retailers choose the SBLDSS as the best LDS strategy [36], and when retailers' BT input costs are high, e-retailers choose the OLDSS as the best LDS strategy.

(2) Under the two LDS strategies, the production and transaction of the new products and the recycled products are positively correlated with the GBS quota. Under the two LDS strategies, there is a positive correlation between the profit of the enterprise in the E-CLSC and the GBS quota [16], which promotes the overall development of the E-CLSC and enhances the willingness of the e-retailers to invest in BT [48]. Thus, the government must provide subsidies to the e-retailers for the investment in BT.

Based on the above conclusions, we have the following management insights:

(1) Although BT investment of the e-retailers can increase their own profits, e-retailers ought to have a passionate attitude towards BT investment and actively invest in BT technology. The increase in the BT input cost can cause the consumption of the customers in the markets to be restricted, the profits of the other members of the E-CLSC to be damaged, and the level of social welfare to be reduced.

(2) The government's subsidy of the BT investment can increase the customers' consumption in the market, stabilize the income of the E-CLSC members by increasing product sales, and promote the overall development of the E-CLSC. Therefore, the government must provide subsidies for the investment of BT within its financial scope.

(3) E-retailers can regulate the optimal LDS strategy based on the BT input cost. When the BT input cost of the e-retailer is low, the selling price under the SBLDSS is much higher than that under the OLDSS, so the e-retailers obtain a higher benefit under the SBLDSS and the e-retailers can establish their own logistics distribution system. On the contrary, when the BT input cost of the e-retailer is high, the gap between the sales price under the SBLDSS and the sales price under the OLDSS is reduced, and e-retailers obtain greater benefits under the OLDSS; thus, it is recommended that e-retailers choose the OLDSS.

In this paper, we analyzed the impact of e-retailers' BT input costs and the GBS quota on equilibrium decisions and LDS strategy selection in the E-CLSC network, but there are still some shortcomings of this study. First, we only analyzed two LDS strategies, the OLDSS and the SBLDSS. Thus, we shall discuss other logistics distribution strategies, such as the hybrid LDS strategy, in our future research. Second, we only analyzed the impact of government subsidies for the investment of BT on the transaction quantities of the decision makers. Thus, we shall discuss other subsidies, such as price subsidies and innovation subsidies, for the investment of BT in our future research.

Author Contributions: This paper was completed by Y.Z., C.L. and K.-H.W.; Y.Z. and C.L. constructed the model and wrote the paper. K.-H.W. checked the draft and corrected the language. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (grant number 71901129).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: We would like to thank the anonymous reviewers for their constructive comments.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

From Equation (1), the Hessian matrix is

$$H_m = \begin{bmatrix} -\dfrac{\partial^2 f_m(Q^1)}{\partial q_m^{new\ 2}} & 0 & 0 \\ 0 & -\dfrac{\partial^2 c_{mn}(q_{mn})}{\partial q_{mn}^2} & 0 \\ 0 & 0 & -\dfrac{\partial^2 c_{km}(q_{km})}{\partial q_{km2}^2} - \dfrac{\partial^2 c_m\left(\sum\limits_{k=1}^{K} q_{km}\right)}{\partial q_{km}^2} - \dfrac{\partial^2 \varphi_m\left(\beta\sum\limits_{k=1}^{K} q_{km}\right)}{\partial q_{km}^2} - \dfrac{\partial^2 c_{m,D}\left((1-\beta)\sum\limits_{k=1}^{K} q_{km}\right)}{\partial q_{km}^2} \end{bmatrix}.$$

From the convexity assumption in Assumption 7, we know that the Hessian matrix is a negative definite matrix; hence, Proposition 1 is proven.

Appendix B

By introducing the Lagrange multipliers ω_m and ϑ_m into Constraints (2) and (3), respectively, we obtain the Lagrange function of (1) as follows:

$$\begin{gathered} L_m = -\sum_{n=1}^{N} \rho_{mn} q_{mn} + f_m(Q^1) + \sum_{n=1}^{N} c_{mn}(q_{mn}) + \sum_{k=1}^{K} \rho_{km} q_{km} + \sum_{k=1}^{K} c_{km}(q_{km}) + c_m\left(\sum_{k=1}^{K} q_{km}\right) \\ +\phi_m\left(\beta\sum_{k=1}^{K} q_{km}\right) + \eta(1-\beta)\sum_{k=1}^{K} q_{km} + c_{m,D}\left(\overline{\beta}\sum_{k=1}^{K} q_{km}\right) + \omega_m\left(\sum_{n=1}^{N} q_{mn} - q_m^{new} - \beta\sum_{k=1}^{K} q_{km}\right) \\ +\vartheta_m\left(\alpha\sum_{n=1}^{N} q_{mn} - \sum_{k=1}^{K} q_{km}\right). \end{gathered} \tag{A1}$$

Using the first-order derivatives of (A1) with respect to each of the decision variables, q_m^{new}, q_{mn}, q_{km}, ω_m, and ϑ_m, respectively, we obtain the first-order optimality conditions as follows:

$$\begin{gathered} \frac{\partial L_m}{\partial q_m^{new}} = \frac{\partial f_m(Q^1)}{\partial q_m^{new}} - \omega_m, \\ \frac{\partial L_m}{\partial q_{mn}} = \frac{\partial c_{mn}(q_{mn})}{\partial q_{mn}} + \omega_m + \alpha\vartheta_m - \rho_{mn}, \\ \frac{\partial L_m}{\partial q_{km}} = \rho_{km} + \frac{\partial c_{km}(q_{km})}{\partial q_{km}} + \frac{\partial c_m\left(\sum\limits_{k=1}^{K} q_{km}\right)}{\partial q_{km}} + \frac{\partial \phi_m\left(\beta\sum\limits_{k=1}^{K} q_{km}\right)}{\partial q_{km}} + \eta(1-\beta) + \frac{\partial c_{m,D}\left((1-\beta)\sum\limits_{k=1}^{K} q_{km}\right)}{\partial q_{km}} - \beta\omega_m - \vartheta_m, \\ \frac{\partial L_m}{\partial \omega_m} = \sum_{n=1}^{N} q_{mn} - q_m^{new} - \beta\sum_{k=1}^{K} q_{km}, \\ \frac{\partial L_m}{\partial \vartheta_m} = \alpha\sum_{n=1}^{K} q_{mn} - \sum_{k=1}^{K} q_{km}. \end{gathered}$$

Then, we obtain VI (4); hence, Theorem 1 is proven.

Appendix C

By introducing the Lagrange multipliers σ_n into Constraint (6), we obtain the Lagrange function of (5) as follows:

$$\begin{aligned} L_n = -\sum_{o=1}^{O}\sum_{k=1}^{K}\rho_{nok}q_{nok} - s_B\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok} + \sum_{m=1}^{M}\rho_{mn}q_{mn} + \sum_{o=1}^{O}\sum_{k=1}^{K}r_{nok}q_{nok} + c_n\left(Q^2\right) + c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok},\theta\right) \\ +\sigma_n\left(\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok} - \sum_{m=1}^{M}q_{mn}\right). \end{aligned} \tag{A2}$$

Applying the first-order derivatives of (A2) of q_{mn}, q_{nok}, and σ_n, respectively, we obtain the first-order optimality conditions as follows:

$$\begin{aligned} \frac{\partial L_n}{\partial q_{mn}} &= \rho_{mn} + \frac{\partial c_n\left(Q^2\right)}{\partial q_{mn}} - \sigma_n = 0, \\ \frac{\partial L_n}{\partial q_{nok}} &= r_{nok} + \frac{\partial c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok},\theta\right)}{\partial q_{nok}} + \sigma_n - \rho_{nok} - s_B = 0, \\ \frac{\partial L_n}{\partial \sigma_n} &= \sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok} - \sum_{m=1}^{M}q_{mn} = 0. \end{aligned}$$

By deriving the above optimality conditions with respect to θ, we obtain

$$\begin{aligned} \frac{\partial^2 L_n}{\partial q_{mn}\partial\theta} + \frac{\partial^2 L_n}{\partial {q_{mn}}^2}\frac{\partial q_{mn}}{\partial\theta} + \frac{\partial^2 L_n}{\partial q_{mn}\partial q_{nok}}\frac{\partial q_{nok}}{\partial\theta} + \frac{\partial^2 L_n}{\partial q_{mn}\partial\sigma_n}\frac{\partial\sigma_n}{\partial\theta} = 0, \\ \frac{\partial^2 L_n}{\partial q_{nok}\partial\theta} + \frac{\partial^2 L_n}{\partial q_{nok}\partial q_{mn}}\frac{\partial q_{mn}}{\partial\theta} + \frac{\partial^2 L_n}{\partial {q_{nok}}^2}\frac{\partial q_{nok}}{\partial\theta} + \frac{\partial^2 L_n}{\partial q_{nok}\partial\sigma_n}\frac{\partial\sigma_n}{\partial\theta} = 0, \\ \frac{\partial^2 L_n}{\partial\sigma_n\partial\theta} + \frac{\partial^2 L_n}{\partial\sigma_n\partial q_{mn}}\frac{\partial q_{mn}}{\partial\theta} + \frac{\partial^2 L_n}{\partial\sigma_n\partial q_{nok}}\frac{\partial q_{nok}}{\partial\theta} + \frac{\partial^2 L_n}{\partial {\sigma_n}^2}\frac{\partial\sigma_n}{\partial\theta} = 0, \end{aligned}$$

which imply that

$$\frac{\partial q_{mn}}{\partial\theta} = \frac{\partial q_{nok}}{\partial\theta} = -\frac{\dfrac{\partial^2 c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok},\theta\right)}{\partial q_{nok}\partial\theta}}{\dfrac{\partial^2 c_n\left(Q^2\right)}{\partial {q_{mn}}^2} + \dfrac{\partial^2 c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok},\theta\right)}{\partial {q_{nok}}^2}}.$$

Similarly, we can obtain

$$\frac{\partial q_{mn}}{\partial s_B} = \frac{\partial q_{nok}}{\partial s_B} = \frac{1}{\frac{\partial^2 c_n\left(Q^2\right)}{\partial {q_{mn}}^2} + \frac{\partial^2 c_{n,B}\left(\sum_{o=1}^{O}\sum_{k=1}^{K}q_{nok},\theta\right)}{\partial {q_{nok}}^2}}.$$

From Assumptions 5–7, we can obtain $\frac{\partial q_{mn}}{\partial\theta} = \frac{\partial q_{nok}}{\partial\theta} < 0$, and $\frac{\partial q_{mn}}{\partial s_B} = \frac{\partial q_{nok}}{\partial s_B} > 0$. Hence, Property 1 is proven.

Appendix D

From Equation (8), we obtain

$$\frac{\partial^2 \pi_o}{\partial {r_{nok}}^2} = -\frac{\partial^2 c_{nok}(r_{nok})}{\partial {r_{nok}}^2}$$

From Assumption 7, we obtain $-\frac{\partial^2 c_{nok}(r_{nok})}{\partial {r_{nok}}^2} < 0$. Hence, Proposition 3 is proven.

References

1. *In 2023, the Cumulative Volume of Express Delivery Business in China Reached 132.07 Billion Pieces*; OJL: Beijing, China, 2024; Available online: https://baijiahao.baidu.com/s?id=1788754101905552615&wfr=spider&for=pc (accessed on 25 February 2024).
2. Wu, Q.; Mu, Y.; Feng, Y. Coordinating contracts for fresh product outsourcing logistics channels with power structures. *Int. J. Prod. Econ.* **2015**, *160*, 94–105. [CrossRef]
3. Zheng, K.; Zhang, Z.; Song, B. E-commerce logistics distribution mode in big-data context: A case analysis of JD. COM. *Ind. Market. Manag.* **2020**, *86*, 154–162. [CrossRef]
4. Li, L.; Li, G. Integrating logistics service or not? The role of platform entry strategy in an online marketplace. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *170*, 102991. [CrossRef]
5. He, P.; Zhang, S.; He, C. Impacts of logistics resource sharing on B2C E-commerce companies and customers. *Electron. Commer. Res. Appl.* **2019**, *34*, 100820. [CrossRef]
6. Yu, J.; Zhou, C.; Leng, G. Is It Always Advantageous to establish self-built logistics for online platforms in a competitive retailing setting? *IEEE T. Eng. Manag.* **2024**, *71*, 1726–1743. [CrossRef]
7. He, Y.; Zhou, F.; Qi, M.; Wang, X. Joint distribution: Service paradigm, key technologies and its application in the context of Chinese express industry. *Int. J. Logist.-Res. App.* **2020**, *23*, 211–227. [CrossRef]
8. Niu, B.; Zhang, J.; Mu, Z. IoT-enabled delivery time guarantee in logistics outsourcing and efficiency improvement. *Int. J. Prod. Res.* **2023**, *61*, 4135–4156. [CrossRef]
9. Morkunas, V.J.; Paschen, J.; Boon, E. How blockchain technologies impact your business model. *Bus. Horiz.* **2019**, *62*, 295–306. [CrossRef]
10. Hou, P.; Zhang, C.; Li, Y. The interplay of manufacturer encroachment and blockchain adoption to combat counterfeits in a platform supply chain. *Int. J. Prod. Res.* **2024**, *62*, 1382–1398. [CrossRef]
11. Nofer, M.; Gomber, P.; Hinz, O.; Schiereck, D. Blockchain. *Bus. Inform. Syst. Eng.* **2017**, *59*, 183–187. [CrossRef]
12. Zhang, X.; Li, Z.; Li, G. Impacts of blockchain-based digital transition on cold supply chains with a third-party logistics service provider. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *170*, 103014. [CrossRef]
13. Ar, I.M.; Erol, I.; Peker, I.; Ozdemir, A.I.; Medeni, T.D.; Medeni, I.T. Evaluating the feasibility of blockchain in logistics operations: A decision framework. *Expert. Syst. Appl.* **2020**, *158*, 113543. [CrossRef]
14. Noor, A. Adoption of blockchain technology facilitates a competitive edge for logistic service providers. *Sustainability* **2022**, *14*, 15543. [CrossRef]
15. Choi, T.-M.; Luo, S. Data quality challenges for sustainable fashion supply chain operations in emerging markets: Roles of blockchain, government sponsors and environment taxes. *Transp. Res. Transp. Res. Part E Logist. Transp. Rev.* **2019**, *131*, 139–152. [CrossRef]
16. Zhong, Y.; Yang, T.; Yu, H.; Zhong, S.; Xie, W. Impacts of blockchain technology with government subsidies on a dual-channel supply chain for tracing product information. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *171*, 103032. [CrossRef]
17. Guide, V.D.R., Jr.; VanWassenhove, L.N. Closed-loop supply chains: An introduction to the feature issue (part 1). *Prod. Oper. Manag.* **2006**, *15*, 345–350. [CrossRef]
18. Hammond, D.; Beullens, P. Closed-loop supply chain network equilibrium under legislation. *Eur. J. Oper. Res.* **2007**, *183*, 895–908. [CrossRef]
19. Nash, J.R.J.F. Equilibrium points in n-person games. *Proc. Natl. Acad. Sci. USA* **1950**, *36*, 48–49. [CrossRef]
20. Fu, R.; Qiang, Q.P.; Ke, K.; Huang, Z. Closed-loop supply chain network with interaction of forward and reverse logistics. *Sustain. Prod. Consump.* **2021**, *27*, 737–752. [CrossRef]
21. Wu, H.; Xu, B.; Zhang, D. Closed-loop supply chain network equilibrium model with subsidy on green supply chain technology investment. *Sustainability* **2019**, *11*, 4403. [CrossRef]
22. Saberi, S.; Cruz, J.M.; Sarkis, J.; Nagurney, A. A competitive multiperiod supply chain network model with freight carriers and green technology investment option. *Eur. J. Oper. Res.* **2018**, *266*, 934–949. [CrossRef]
23. Zhang, G.; Zhang, X.; Sun, H.; Zhao, X. Three-echelon closed-loop supply chain network equilibrium under cap-and-trade regulation. *Sustainability* **2021**, *13*, 6472. [CrossRef]
24. Yang, Y.; Goodarzi, S.; Jabbarzadeh, A.; Fahimnia, B. In-house production and outsourcing under different emissions reduction regulations: An equilibrium decision model for global supply chains. *Transp. Res. Part E Logist. Transp. Rev.* **2022**, *157*, 102446. [CrossRef]
25. Hong, I.-H.; Chen, P.-C.; Yu, H.-T. The effects of government subsidies on decentralized reverse supply chains. *Int. J. Prod. Res.* **2016**, *54*, 3962–3977. [CrossRef]
26. Yang, G.; Wang, Z.; Li, X. The optimization of the closed-loop supply chain network. *Transp. Res. Part E Logist. Transp. Rev.* **2009**, *45*, 16–28. [CrossRef]
27. Qiang, Q.; Ke, K.; Anderson, T.; Dong, J. The closed-loop supply chain network with competition, distribution channel investment, and uncertainties. *Omega* **2013**, *41*, 186–194. [CrossRef]
28. Chan, C.; Zhou, Y.; Wong, K. A dynamic equilibrium model of the oligopolistic closed-loop supply chain network under uncertain and time-dependent demands. *Transp. Res. Part E Logist. Transp. Rev.* **2018**, *118*, 325–354. [CrossRef]
29. Yang, Y.; Goodarzi, S.; Market, A.; Fahimnia, B. Carbon cap-and-trade schemes in closed-loop supply chains: Why firms do not comply? *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *156*, 102486. [CrossRef]

30. Cheng, P.; Wang, T. Optimizing the emission control policies and trade-in program effects: A carbon-constrained closed-loop supply chain network model. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *179*, 103311. [CrossRef]
31. Zhou, Y.; Hou, M.; Wong, K.H. The optimal remanufacturing strategy of the closed-loop supply chain network under government regulation and the manufacturer's design for the environment. *Sustainability* **2023**, *15*, 7342. [CrossRef]
32. Giri, B.; Sarker, B.R. Improving performance by coordinating a supply chain with third party logistics outsourcing under production disruption. *Comput. Ind. Eng.* **2017**, *103*, 168–177. [CrossRef]
33. Buldeo Rai, H.; Verlinde, S.; Macharis, C.; Schoutteet, P.; Vanhaverbeke, L. Logistics outsourcing in omnichannel retail. *Int. J. Phys. Distr. Log.* **2019**, *49*, 267–286. [CrossRef]
34. Liu, H.; Xu, T.; Jing, S.; Liu, Z.; Wang, S. The interplay between logistics strategy and platform's channel structure design in B2C platform market. *Eur. J. Oper. Res.* **2023**, *310*, 812–833. [CrossRef]
35. Cao, K.; Xu, Y.; Hua, Y.; Choi, T.-M. Supplier or co-optor: Optimal channel and logistics selection problems on retail platforms. *Eur. J. Oper. Res.* **2023**, *311*, 971–988. [CrossRef]
36. Dong, C.; Huang, Q.; Pan, Y.; Ng, C.T.; Liu, R. Logistics outsourcing: Effects of greenwashing and blockchain technology. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *170*, 103015. [CrossRef]
37. Wang, L.; Chen, J.; Lu, Y. Manufacturer's channel and logistics strategy in a supply chain. *Int. J. Prod. Econ.* **2022**, *246*, 108415. [CrossRef]
38. Zhang, S.; Lee, J.-H. Analysis of the main consensus protocols of blockchain. *ICT Express* **2020**, *6*, 93–97. [CrossRef]
39. Modak, N.M.; Senapati, T.; Simic, V.; Pamucar, D.; Saha, A.; Cárdenas-Barrón, L.E. Managing a sustainable dual-channel supply chain for fresh agricultural products using blockchain technology. *Expert. Syst. Appl.* **2024**, *244*, 122929. [CrossRef]
40. Wang, M.; Li, B.; Song, D. The impact of blockchain on restricting the misuse of green loans in a capital-constrained supply chain. *Eur. J. Oper. Res.* **2024**, *314*, 980–996. [CrossRef]
41. Niu, B.; Dong, J.; Liu, Y. Incentive alignment for blockchain adoption in medicine supply chains. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *152*, 102276. [CrossRef]
42. Liu, X.; Shah, R.; Shandilya, A.; Shah, M.; Pandya, A. A systematic study on integrating blockchain in healthcare for electronic health record management and tacking medical supplies. *J. Clean. Prod.* **2024**, *447*, 141371. [CrossRef]
43. Zhang, Q.; Li, Y.; Hou, P.; Wang, J. Price signal or blockchain technology? Quality information disclosure in dual-channel supply chains. *Eur. J. Oper. Res.* **2024**, *316*, 15–137. [CrossRef]
44. Wang, M.; Yang, F.; Shan, F.; Guo, Y. Blockchain adoption for combating remanufacturing perceived risks in a reverse supply chain. *Transp. Res. Transp. Res. Part E Logist. Transp. Rev.* **2024**, *183*, 103448. [CrossRef]
45. Zhang, X.; Zheng, H.; Zheng, X. Impact of government fund policy and blockchain technology on closed-loop supply chains in textile and apparel industry. *J. Clean. Prod.* **2024**, *434*, 140037. [CrossRef]
46. Dai, B.; Niu, Y.; Xie, X.; Li, J. Interactions of traceability and reliability optimization in a competitive supply chain with product recall. *Eur. J. Oper. Res.* **2021**, *290*, 116–131. [CrossRef]
47. Wang, J.; Liu, J.; Wang, F.; Yue, X. Blockchain technology for port logistics capability: Exclusive or sharing. *Transport. Res. B-Meth.* **2021**, *149*, 347–392. [CrossRef]
48. Zhang, P.; Wu, H.; Li, H.; Zhong, B.; Fung, I.W.H.; Lee, Y.Y.R. Exploring the adoption of blockchain in modular integrated construction projects: A game theory-based analysis. *J. Clean. Prod.* **2023**, *408*, 137115. [CrossRef]
49. Hamidoğlu, A.; Gül, Ö.M.; Kadry, S.N. A game-theoretical approach for the adoption of government-supported blockchain application in the IoT-enabled agricultural supply chain. *Internet Things* **2024**, *26*, 101163. [CrossRef]
50. Savaskan, R.C.; Bhattacharya, S.; Van Wassenhove, L.N. Closed-loop supply chain models with product remanufacturing. *Manag. Sci.* **2004**, *50*, 239–252. [CrossRef]
51. Dong, Z. Construction of mobile E-commerce platform and analysis of its impact on E-commerce logistics customer satisfaction. *Complexity* **2021**, *2021*, 6636415. [CrossRef]
52. Kinderlehrer, D.; Stampacchia, G. *An Introduction to Variational Inequalities and Their Applications*; Academic Press: Cambridge, MA, USA, 1980.
53. Korpelevich, G.M. The extragradient method for finding saddle points and other problems. *Matecon* **1976**, *12*, 747–756.