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Multi-Period E-Closed-Loop Supply Chain Network Considering Consumers' Preference for Products and AI-Push

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Abstract: The remanufacturing industry plays a significant role to improve the utilization of resources and contribute to environmental protection and sustainable development. E-commerce channel (e-channel) has become an important retail channel. The multi-period closed-loop supply chain network of electronic channels (E-CLSCN) is studied. Moreover, this study considers the influence of consumers' preference for products and artificial intelligence push (AI-push) on network balance under the conditions of dynamic and static. The network consists of manufacturers, remanufacturers, and demand markets. Remanufacturers are responsible for collecting and remanufacturing. The multi-period E-CLSCN model is established through variational inequalities. The study finds that whether dynamic or static, consumers' preference for new products (NP) has positively correlated with the profits of manufacturers and the whole E-CLSCN. Consumers' preference for remanufacturer products (RP) has only positively correlated with the profits of remanufactures. In the aspect of AI-push, the manufacturers' AI-push has positively correlated with the profits of the entire players of E-CLSCN, while the remanufacturers' AI-push has only positively correlated with the profits of the remanufacturers. Also, considering the multi-period, the sensitivity of the demand markets for the investment of manufacturers' and remanufacturers' AI-push gradually reduces, and the marginal benefit of AI-push gradually decreases. Finally, this paper addresses interesting managerial insights from the perspective of government and enterprises. Under the dual objectives of environmental protection and economic interests of enterprises, this study provides a reference for governments and enterprises to develop relevant dynamic policies. Namely, the government formulates dynamic environmental protection measures, and enterprises formulate dynamic strategic plans and implement government policies. While promoting the management level of E-CLSCN, it effectively boosts the development of the remanufacturing industry and recycling sustainable economy.

Keywords: consumers' preference for products; AI-push; sustainable development; e-commerce channel (e-channel); multi-period e-channel closed-loop supply chain network (E-CLSCN)

1. Introduction

Currently, with the increasing demand for resources in human society, the contradiction between environmental pollution and energy exhaustion is becoming increasingly serious [1]. In order to alleviate this contradiction, the United States has established a 3R (Reuse, Recycle, Remanufacturer) system from the perspective of sustainable development. However, Japan has also established a 3R (Reduce, Reuse, Recycle) system. It can be said that remanufacturing is a vital section to realize the sustainable development of resources. Remanufacturing is a process of high-tech repair and renovation of end-of-life (EOL) products. Generally, the quality and performance of RP are required no less than that of new products (NP) [2,3]. Remanufacturing is the future industry which serves

as the second promotion of human industrial civilization. The remanufacturing industry means the transformation of human industrial civilization and its industrial philosophical ideas are thrift, green and sustainable development.

Closed-loop supply chain (CLSC) management is a brand-new management mode, which adapts to the reform of sustainable development [4]. Also, CLSC management integrates the traditional forward supply chain with the reverse supply chain organically, forming a closed-loop process of "resources-production-consumption-collection-remanufacturing" [1,5]. Moreover, the core idea of CLSC is to emphasize the simultaneous improvement of social and environmental benefits to realize the sustainable development of economy and society, while achieving economic benefits. Until now, there are two kinds of research on optimal model of the CLSC system. Respectively, they are simple structure CLSC system (one-to-one, one-to-many, or many-to-one) and complex structure closed-loop supply chain network (CLSCN), as seen in Figure 1. Classical research mostly considers the simple structure CLSC system [1,6,7]. In a multi-level supply chain, there are often multiple members and similar members of the same level. Different multi-layer members with different functions (e.g., multiple manufacturers, remanufacturers, retailers, etc.) constitute a complex CLSCN structure [8–10], such as iPhone, Samsung mobile phone, Huawei mobile phone, etc. As for the demand markets, there are also many demand markets with the same or similar demand, such as Chinese and American consumers. Based on this background, this paper studies the CLSCN equilibrium problem. Also, the behavior of enterprise is often multi-period and durable in reality, so it has more practical significance to study the multi-period CLSCN.

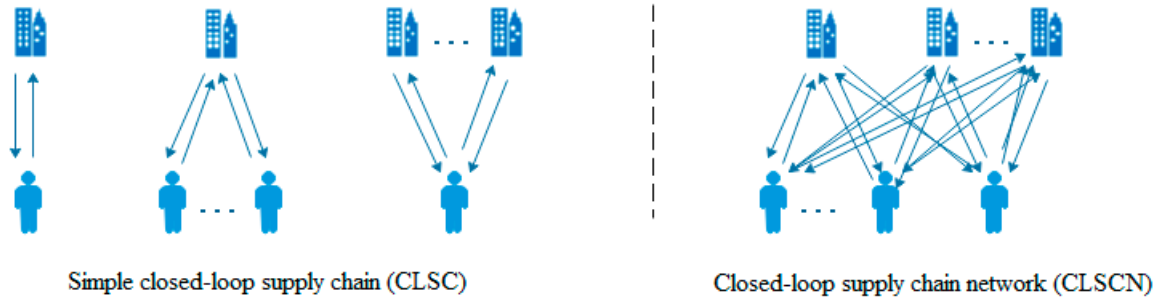

Figure 1. The closed-loop supply chain (CLSC) and closed-loop supply chain network (CLSCN).

In the CLSCN, manufactures (remanufactures) sell NP (RP) through some special channels, mainly including traditional retail-channel and e-channel (B2C) [11]. With the rapid development of network technology, e-channel is attracting an increasing number of attention from enterprises and consumers [12,13]. According to the online retailer report (www.alibaba.com), as shown in Figure 2, the rapid development of the retail industry of e-channel sales has far exceeded the total retail sales. Currently, manufactures (remanufactures) retail their NP (RP) through online sales platforms such as Taobao, Tmall, and Amazon, etc. In comparison to the traditional retail channels, the e-channel direct marketing channels have the advantages of fewer middlemen, higher control efficiency, and lower inventory risk [13,14]. There is no need to have specialized retailers, which effectively reduces the cost of the CLSCN. Also, the lack of intermediate retail environment can reduce environmental impacts in some ways. Then, how does this paper describe the cooperation and competition among the enterprises of the CLSCN under the e-channel, to improve the profits and competitive advantage of enterprises? Hence, this paper is studying the E-CLSCN.

At present, the concept of sustainable development of environment and resources has penetrated the minds of consumers. Consumers, together with the government and enterprises, have joined in the ranks of resource protection and have begun to reflect on the negative impact of rapid economic development on the environment. Consumer's awareness of environmental protection and the concept of pursuing development have also significantly changed. Consumers not only pay attention to the purchase of NP but also begin to pay attention to RP [2,15,16]. On the e-channel, consumers

can purchase either NP or RP with the same functions. Consumers' preference is individualized ones which reflect consumers' willingness to pay for different products or services, which is also an essential factor that affects market demand [17]. Due to the different levels of knowledge and consumption habits of consumers, consumers will have a separate evaluation of NP and RP [18]. The results of 655 valid questionnaires received on the Internet (www.wjx.com) shows that consumers have a preference for RP and NP. To promote environmental sustainability, 45.5% of consumers are willing to pay for RP at a higher price than NP (seen as in Appendix A). However, consumers still have insufficient mobility, and manufacturers and remanufacturers lack understanding of the impact of consumer preferences on companies. The purchasing behavior of consumers for RP still encounters some problems, such as understanding of RP, insufficient motivation, etc. Under the E-channel, how does consumers' preference for products affect the economic performance of manufacturers and remanufacturers, and what should enterprises do?

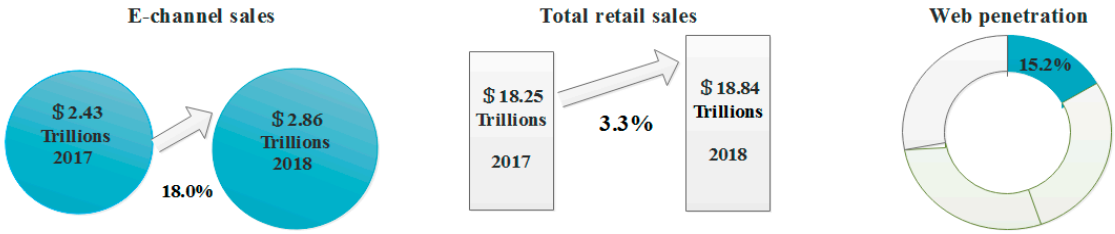

Figure 2. E-channel sales, web penetration and total retail sales.

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In the fierce competition of e-channel between manufacturers and remanufactures, they often conduct promotional actions to increase the sales volume of their products [19]. With the rapid development of e-channel, AI-push has become a new advertising style for the product of e-channel. At the Global AI and Robot Summit in 2018, Ma proposed that "AI promotes the development of the supply chain and will completely change the traditional supply chain. A smarter supply chain will be the development trend of the future supply chain". AI-push will show the content of the product in the process of consumers browsing the Internet. The advantage of AI-push is that it can choose a specific time to push products according to consumers' living habits and time habits, while the enterprises only need to pay a particular fee for the e-channel platform. Thus, it can be seen that AI-push is an indispensable factor in E-CLSCN. So how does AI-push affect the profits of manufacturers and remanufacturers, and how should manufacturers and remanufacturers deal with it?

In summary, E-CLSCN has developed rapidly. However, current research is still not mature enough (Table 1). E-CLSCN can increase the sustainability of resources. Firstly, The B2C marketing mode of E-CLSCN effectively reduces the intermediate costs of manufacturers and remanufacturers, due to inconsideration of intermediate retailer behavior [19,20]. At a deeper level, E-CLSCN can decrease the impact of retailers' action on the environment, which helps to cut down the number of enterprises in the environment and reduces the environmental pollution caused by enterprise behavior. Secondly, in E-CLSCN, the manufacturers (remanufacturers) and the demand market are in direct contact, which can effectively avoid the problem of information asymmetry between the manufacturers (remanufacturers) and the market demands due to the participation of the retailers. Thirdly, under the symmetry of information, remanufacturers can more effectively develop dynamic AI-push, collecting strategies, and remanufacturing strategies in response to consumers' preference for products. So, the E-CLSCN will help to upgrade the remanufacturing industry, improve the utilization of resources, and then achieve economic and environmental sustainability.

However, how do consumers' preference for products and AI-push affect the economic performance of manufacturers and remanufacturers in E-CLSCN? What should enterprises and governments do, while taking into account economic interests and environmental sustainability?

The purpose of this paper is to study and solve the following problems:

- For economic performance, when consumers' preference for products and AI-push are static and dynamic situations, how do they affect the profits of manufacturers and remanufacturers?
- For enterprise management, how can manufacturers and remanufacturers positively respond and feedback for the influence of E-CLSCN through consumers' preference for products and AI-push, to promote the stable operation of enterprises and the whole E-CLSCN?
- For environmental sustainability, how should the government and enterprises take effective measures to promote the development of E-CLSCN, to improve the sustainable use of resources?

To solve the above purposes, firstly, this article starts with the background of multi-period E-CLSCN of recycling and remanufacturing by remanufacturers. Then, the effects of consumers' preference for products (NP, RP) and manufacturers' (remanufacturers') AI-push on E-CLSCN equilibrium is studied. Secondly, the static and dynamic situation of consumers' preference for products (NP, RP) and AI-push are also considered. Thirdly, based on the theory of nonlinear-programming and Nash equilibrium in non-cooperative game, the multi-period E-CLSCN is modeled by using the method of variational inequalities. From the static and dynamic aspects, numerical examples are used to analyze the sensitivity of consumers' preference for products and AI-push to E-CLSCN equilibrium. Finally, the results are discussed, and management implications are put forward from the perspective of enterprises and governments.

The research contributions of this paper are as follows: (1) Through reading the research of Govindan et al. [1],Savadkoohi et al. [21], Nagurney et al. [22], Qiang [10], Wang et al. [23], etc., current, abundant research results have been achieved in simple CLSN and CLSCN (seen as in literature review). However, by comparing the existing literature (Table 1), the research of considering consumers' preference for product, AI-push and multi-period on E-CLSCN is still blank. This paper aims to fill the blank in the literature. (2) Although a lot of studies has been done on consumers' preference for products or promotional behavior on e-channel (Table 1), the current researches are not perfect in these two factors and dynamic analysis. In this paper, a more comprehensive sensitivity analysis is carried out by comparing the dynamic state with the static state. (3) Through discussing the results of sensitivity analysis, management inspiration is given from the perspective of enterprises and governments, and specific dynamic measures are provided to promote the sustainable development of the remanufacturing industry.

The structure of this paper is as follows. In Section 2, relevant literature is reviewed and compared. In Section 3, the problem is described in detail, including assumptions and annotations. In Section 4, the E-CLSCN model is established by using the method of variational inequality. In Section 5, the numerical

examples and the results are illustrated. In Section 6, the results and managerial insights are discussed. Finally, in Section 7, the conclusions, limitations and future directions are given.

2. Literature Review

2.1. Supply Chain Considering Consumers' Preference

The study of supply chain considering consumers' preference, the current mainstream research, is mainly based on the perspective of consumers' preference for the channel [24] and consumers' preference for products. Consumers' preference for products mostly includes consumer's preferences for low carbon (green) products and consumer's preference for remanufactured (new) products (NP, RP). In the perspective of consumer's preferences for low-carbon (green) products, Du et al. [25] adopted a new emission-sensitive demand function considering consumers' preferences for low-carbon products and found that channel profit and emission reduction were positively correlated with consumers' preferences for low carbon product. Wang et al. [26] found that wholesale premium contracts could promote the emission reduction of supply chain enterprises and increase the profit of the supply chain when consumers' preferences for low-carbon products was high. Ji et al. [27] studied the effect of consumers' preferences for low-carbon products on dual-channel situations and found that the consumers' low-carbon preferences was benefits for manufacturer. Tong et al. [28] studied the consumers' preferences for low-carbon products and government carbon emission cap on supply chain. The research of Du et al. [25], Wang et al. [26], Ji et al. [27] and Tong et al. [28] considered from the perspective of determining demand. Meanwhile, in terms of random demand, Peng et al. [29] analyzed the problem of supply chain coordination in the case of consumers' preferences for low-carbon product and uncertain products faced by manufacturers. However, they did not consider the consumers' preference for products (NP, RP).

In the perspective of consumers' preferences for products (NP, RP), general research includes the impact of consumers' preference on firm pricing, random and determining demand, optimal decision making, the influencing factors of consumers' preference, and the impact of enterprises' behavior on consumers' preference. Debo et al. [15] studied the remanufacturing technology selection and the pricing decision-making of the remanufactured supply chain considering the difference between consumers' evaluation of the NP and RP. Ferrer and Swaminathan [2] established a differential pricing model for reverse supply chain considering the different consumers' preference for products. Meanwhile, Abbey et al. [3] studied the product pricing from a simple monopoly scenario to a complex scenario involving remanufacturing based on consumers' preference for new and remanufactured products. By employing an Internet questionnaire, Matsumoto et al. [16] analyzed consumers' preference of remanufactured auto parts (RAPs) in Southeast Asian countries and revealed influencing factors on consumers' RAP preference. Also, Zhao et al. [30] considered the government subsidies based on consumers' preference for remanufactured products, then showed it was more beneficial for the remanufacturer to share a certain proportion of subsidies with consumers. Zhu and Yu [31] studied a supply chain considering consumers' preference for RP and green products. Moreover, Xu and Wang [32] took consumers' satisfaction as the objective function to analyze the influence of consumers' preference for RP. By comparing with the above literature, this study is the same as literature Ferrer and Swaminathan [2], Debo et al. [15], Zhao et al. [30], and considers the impact of consumers' preference for products on enterprises' profits. The difference is that Ferrer and Swaminathan [2], Debo et al. [15], Zhao et al. [30], they did analyze from a dynamic perspective. However, the dynamic situation is considered in this paper. Different from Ferrer and Swaminathan [2], Debo et al. [15], Matsumoto et al. [16], Zhao et al. [30], Zhu and Yu [31] and Xu and Wang [32], they analyzed from the perspective of pricing, influencing factors and corporate behavior, and analyzed from the perspective of a simple and single-period CLSN. However, this paper analyzes a complex and multi-period CLSCN.

2.2. E-Channel Supply Chain and Promotion Activities under E-Channel

The booming technology has brought about the rise of e-channel. By comparing with traditional retail-channel, the supply chain under the e-channel has fewer advantages of middlemen, high control efficiency, and lower inventory risk. In the perspective of e-channel supply chain, the mainstream includes dual-channel, single-channel, and channel comparisons. From the aspect of dual-channel, Ma et al. [33] established a supply chain model for e-channel and physical-channel, and they discussed the impact of government subsidies on the supply chain. Kong et al. [14] established a CLSC by retailers collecting the EOL products, while they considered the e-channel and the physical-channel, and they analyzed the pricing and service decision on the CLSC. Nie et al. [11] studied the effect of the retailer's distribution channel strategy on retailers after traditional retailers implement e-channel. Considering a single-channel with only e-channel, Nagurney et al. [13] studied the supply chain network problem of e-channel under the risk issue of both suppliers and retailers; they concluded equilibrium prices and balanced shipments. Hu et al. [12] analyzed the optimization of agricultural product CLSC under the e-channel, and it was pointed out that the e-channel could better promote the development of agricultural product supply chain. By comparing with the above researches, the literature Nie et al. [11], Hu et al. [12], Kong et al. [14] and Ma et al. [33] only considered a simple CLSC and did not consider a complex CLSCN. Moreover, Nagurney et al. [13] studied the CLSCN, but only considered the single-period situation, and did not consider the multi-period dynamic problem.

With enterprises using e-channel to sell products, scholars have launched research on the enterprise promotion behavior of e-channel as a special channel. The main research includes B2B and B2C promotion, group-purchase promotion, and online-search advertising. Considering the perspective of promotional aspects of B2B and B2C on e-channel, Anand and Aron [20] studied online group buying promotion in B2B and B2C business models earlier. Addressing the perspective of group purchase promotion in e-channel, Li et al. [34] also researched the problem of an online group purchase, and they found the word-of-mouth effect and the learning effect in an online group purchase. Considering the advertising strategy of online search, Li et al. [34] studied the keyword search bidding strategy in the online search of consumers, and they also studied the optimal ranking strategy of keyword bidding strategies and search engines. Jin et al. [35] studied the two sales models of wholesale sales and consignment and studied the optimal promotion strategies of manufacturers promotion and online retailer promotion. Zhou et al. [36] studied the retailer's optimal pricing and cash rebate strategy, and they consisted a third-party online rebate website and an online retailer. For the comparison between online search advertising strategy and traditional retail advertising strategy, Sayedi et al. [19] studied the online search advertising strategies of two competitive corporate and their impact on traditional advertising. By comparing with the above literature [19,20,34–37], it considered the CLSC promotion problem on e-channel from the perspective of a group purchase, online search, enterprise effort and comparison with traditional channel promotions, but they did not consider complex CLSCN. However, this paper is considering the promotion behavior of enterprises in the CLSCN, especially the emerging AI-push, which is very important to improve the performance of enterprises and improve the sustainability of the E-CLSCN.

2.3. Supply Chain Network and Sustainable Supply Chain

Currently, major research directions of supply chain network issues include analysis of influencing factors, demand determination and uncertain demand, and multi-period supply chain network issues. The study of Nagurney et al. [22] established the equilibrium model of supply chain network for the first time and analyzed the optimal decision-making behavior of enterprises in the market. Moreover, they also applied variational inequalities to the solution of relevant models. Using the same research method, Dong et al. [8] extended the supply chain network model to the fuzzy demand. In recent years, scholars have achieved rich research results in the supply chain network, and in terms of multi-period supply chain network issues, Savadkoohi et al. [21] studied the multi-period supply chain network equilibrium considering inventory constraint. In terms of a specific supply chain network, Nagurney

and Dutta [38] studied the supply chain network competition between blood service organizations and hospital enterprises, and they use the variational inequality to obtain equilibrium results. Using the same research method, Wu et al. [39] studied the equilibrium problem of perishable food supply chain network considering time constraints and demand uncertainty. By comparing with the above literature, the research in this paper is the same as the literature [8], and the multi-period situation is considered. However, the literature [8,21,22,38,39] did not consider the CLSCN. The research in this paper is considering the CLSCN of remanufacturing, which can effectively promote the utilization of resources and improve the sustainable development of the economy and environment. With the increasing emphasis on sustainability, scholars have incorporated the concept of sustainability into closed-loop supply chains. In relation to literature reviews on cold supply chain, to achieve these aims, according to Seuring et al. [40] and Shashi et al. [41,42], the introduction could also consider the environment and context-specific factors that have a crucial impact on the supply chain environment sustainability of sustainability orientation and supply chain integration issues. By comparing with the above literature, this paper expands on the research of Dong et al. [8], Savadkoohi et al. [21], Nagurney et al. [22], Nagurney and Dutta [38] and Wu et al. [39] to closed-loop, multi-period and dynamic. Moreover, inspired by Seuring et al. [40] and Shashi et al. [41,42], this article incorporates sustainable ideas into research, that is, the CLSCN.

2.4. CLSC and CLSCN

At present, the research on closed-loop management mainly includes simple structure CLSC and complex structure CLSCN. In the study of the CLSC, Govindan et al. [1] conducted a review of the CLSC, summarized the existing research, compared the existing research and drawn future research directions. In recent years, in the CLSC, some scholars have also paid attention to the impact of consumer behavior on the CLSC [2,15,16,30–33]. Some scholars also considered the impact of recycling on the CLSC. The study of Zhang and Ren [4] considered the collecting and remanufacturing by remanufacturers, and the remanufacturers should pay for the patent fee for manufacturers. Long et al. [6] studied the CLSC consisting of manufacturers and remanufacturers, collecting and remanufacturing behavior by manufacturers, researching the profits of enterprises under centralized decision-making and decentralized decision-making. On the channel management of CLSC, Peng et al. [29] considered a CLSC with two channels. Based on third-party recycling and remanufacturing and government subsidies, it revealed the influence of channel structure and government subsidies on pricing decisions of enterprises. The literature Long et al. [6] and Peng et al. [29] considered the CLSC from the perspective of demand determination. Moreover, in terms of demand uncertainty, Giri et al. [43] analyzed the CLSC in the demand uncertainty and studied the impact of the sales price and warranty period on enterprise's profit from centralized and decentralized decision-making. Finally, they revealed that centralized decision-making was more beneficial to CLSC. By comparing with the above literature, the research hypothesis in this paper is the same as literature Long et al. [6], in the aspect of considering the situation of remanufacturer collecting and remanufacturing [2,3,6,15,16,29–32,43], they did not consider the complex CLSCN structure. This paper considers the supply chain as a complex network structure and a dynamic system.

In the perspective of CLSCN, scholars' research mainly includes consideration of social and government participation, uncertain factors, and consideration of CLSCN equilibrium in consumers' behavior. Hammond and Beullens [44] first started to extend the supply chain network equilibrium to the CLSCN. After the study of Hammond and Beuleens [44], Pedram et al. [45] considered the social responsibility and government participation into CLSCN, and they found that the effective way to improve the total profit of the CLSCN was to consider corporate social responsibility. Allevi et al. [46] researched the impact of European carbon emissions regulations on CLSCN, which included product flows and prices. Wang et al. [23] established a CLSCN equilibrium model and found that government intervention helped the development of the remanufacturing industry. When considering the CLSCN under a uncertain factor, Zhalechian et al. [47] discussed the sustainable design of a closed-loop

location-routing-inventory supply chain network under mixed uncertainty. Based on the uncertain demand for new products and the unknown quantity of returned products, as well as the uncertainty of carbon tax, Haddadsisakht and Ryan [9] analyzed the CLSCN design. Considering the perspective of the multi-period CLSCN, Tao et al. [48] analyzed the impact of carbon tax constraints on the multi-period CLSCN equilibrium from two different carbon emission policies. By comparing the above literature [9,23,44–48], they considered the situation that consumers have no preference. Moreover, for consumers' preference for products on CLSCN, Qiang [10] studied the ability of competition and design for remanufacturing, and they investigated the consumers' perception towards the RP. However, Qiang [10] established that the CLSC network only consists of manufacturers and consumer markets. The node companies in this paper include manufacturers, remanufacturers and demand markets.

In the research method of CLSCN, due to the complexity of the network, multi-node enterprises have a cooperative and competitive relationship. The main research method is based on the theory of nonlinear programming and Nash equilibrium in non-cooperative game, and establishment of a CLSCN model by the method of variational inequality [8–10,21–23,39,44,46,48]. Also, other scholars developed other alternative research methods to solve complex CLSCN problems. Pedram et al. [45] were utilizing the multi-objective mixed-integer linear programming (MILP) model, and the ant colony algorithm was used to solve the model and obtain the equilibrium result. Zhalechian et al. [47] used a method based on the random possibility programming method to deal with network uncertainty, and developed and discussed the hybrid meta-heuristic algorithm and the lower bound. Due to the Stackelberg game relationship between the upper and lower members of the enterprise on the CLSCN, there is a non-cooperative game relationship between same layer members of the network. Variational inequality model can describe the competitive behavior between members at the same level and between members at the upper and lower levels and depict the overall equilibrium state of the system. Therefore, this paper is based on the theory of nonlinear programming and Nash equilibrium in the non-cooperative game, by using the method of variational inequality to model the multi-period E-CLSCN system [8–10,21–23,39,44,46,48]. The system includes multiple manufacturers, remanufacturers and demand markets—analysis of Enterprises' Stackelberg Game and the Equilibrium of E-CLSCN.

According to reviewing relevant research, the following gaps are found in the literature. Firstly, considering the problem of CLSCN for consumers' preference of products, Qiang [10] established that the CLSCN only consists of manufacturers and demand markets, and assumed the collecting and manufacturing by manufacturers. However, with the continuous development of the remanufacturing industry, many professional remanufacturing companies have been produced. The remanufacturing industry in the United States, manufacturers only account for 6%, remanufacturers account for 94%. The research in this paper is different from Qiang [10], and the network consists of manufacturers, remanufacturers and demand markets, and the collecting and remanufacturing by remanufacturers. Secondly, considering the consumers' preference and the promotion of products, the existing literature discussed the static situation [2,3,15,16,19,32,35,36,38]. However, in the actual market, consumers' preference and enterprises' behavior are often not static. The study of this paper from a dynamic and static perspective is more in line with the actual situation. Thirdly, the consumers' preference for products [2,15,16,30–33], e-channel [11,12,14,34], the behavior of corporate promotion under the e-channel [19,20,35–38], CLSCN [9,23,44–48], are explored and then the above questions are combined to be studied, which has not yet been explored. Finally, inspired by the research of Seuring et al. [40] and Shashi et al. [41,42], the sustainable thinking is included in this paper, that is, considering the e-channel can effectively reduce the impact of the middlemen's behavior on the environment, and study the problem the E-CLSCN equilibrium. Table 1 summarizes the main features of this paper in comparison with other related published studies.

Table 1. Main features of this paper in comparison with other related published studies.

Literature	Consumers Preference		E-Channel		Promotional Behavior under E-Channel	Closed Supply Chain		Supply Chain Network			
	NP, RP	Others	E-Channel	Double Channel		Remanufacturer Recycling and Remanufacturing	Recycling and Remanufacturing by Other Players	CLSCN	Supply Chain Network	Multi-Period	Variational Inequality
Govindan et al. [1]				√							
Ferrer and Swaminathan [2], Debo et al. [15], Matsumoto et al. [16], Zhao et al. [30], Zhu and Yu [31] and Xu and Wang [32]	√						√				
Abbey et al. [3] and Zhao et al. [30]	√					√					
Zhang and Ren [4] and Long et al. [6]						√					
Dong et al. [8] and Nagurney et al. [22]									√		√
Haddadsisakht and Ryan [9], Wang et al. [23], Hammond and Beuleens [44], Allevi et al. [46]								√			√
Qiang [10]	√							√			√
Nie et al. [11]			√								
Hu et al. [12]			√								
Nagurney et al. [13]			√						√		
Kong et al. [14]				√			√				
Sayedi et al. [19]				√	√						
Anand and Aron [20], Li et al. [35], Li et al. [36], Jin et al. [36] and Zhou et al. [37]			√		√						
Savadkoohi et al. [21]									√	√	√
Du et al. [25], Wang et al. [26], Tong et al. [28] and Peng et al. [29]		√									
Ji et al. [27]		√		√							
Peng et al. [29]				√			√				
Nagurney and Dutta [3] and Wu et al. [39]									√		√
Giri et al. [43]							√				
Pedram et al. [45]								√			
Zhalechian et al. [47]								√			
Tao et al. [48]								√		√	√
This paper	√		√		√	√		√		√	√

NP: New products; RP: remanufactured products; CLSCN: multi-period closed-loop supply chain network.

3. Assumptions and Notations

3.1. The Problem Statement and Related Assumptions

Firstly, before the problem description, in order to facilitate the reader to understand better the manufacturers and remanufacturers, Table 2 details the manufactures (M) and remanufactures (Re).

Table 2. Detailed comparison of manufactures and remanufactures.

Type	Detailed Description
Production methods	**Re:** The RP is produced by EOL products and using the technology. **M:** The NP is produced by raw materials and using the technology.
Production process	**Re:** Cleaning, disassembly, testing, parts classification, technology selection, remanufacturing, inspection, etc. **M:** Through the technical processing of raw materials produce NP.
Product difference	The performance and quality of NP and RP are similar or identical.
Enterprise characteristics	**Re:** The remanufacturer is engaged in a physical process and a chemical process. For the physical process, the nature of the RP' remains unchanged. For the physical process, the remanufacturers are not engaged in the work of refurbishment and maintenance. EOL products are remanufactured by high-tech. **M:** Belonging to the chemical process, that is, through the technical processing of raw materials to produce new products. Product patent rights, original product pricing rights, primary market control, etc.
Contribution	**Contribution to environmental and sustainability:** **Re:** Save the use of raw materials and improve the utilization of resources. Energy-saving reaches more than 60%, the material consumption is over 70%, and exhaust gas emissions are reduced by more than 80%. **M:** Less contribution to the environment and sustainability. **Contribution to the economy:** **Re:** The cost of RP is only 1/4 or even 1/3 of the cost of NP. **M:** Develop new products that were not available before, promoting economic development and improving people's living standards.
Industry size and distribution	**Industry size and distribution:** **Re:** At present, the global remanufacturing industry is over $140 billion, including engines, auto parts, construction machinery, electrical and electronic products, automobiles, railway equipment, medical equipment, clothing, etc. The largest remanufacturing industry in the world is the United States, followed by Japan, Germany, and China. The distribution of remanufacturing companies around the world, as shown in Figure 3. **M:** There are a large number of manufacturing companies around the world, and there are tens of millions of manufacturing companies registered each year globally. Among them, China 28.57%, the United States 17.89%, Japan 8.16%, Germany 6.05%. **Industry companies:** **Re:** There are a large number of remanufacturing companies in the world, and only 75,000 remanufactured companies are in the United States. The world's largest remanufacturing company is CATERPILLAR, which has 19 plants and 160 production lines in North America, Europe, and the Asia Pacific. The Volvo Remanufacturing Center has eight remanufacturing plants in the world. Lister Petter Remanufacturing Company, ReMobile, Kodak, Xerox, etc. **M:** The number is huge, and there are tens of millions of manufacturing companies registered globally every year.
Relationship	**Competitive relationship:** The function of the products and the consumer group are the same or similar. **Cooperative relationship:** The remanufacturers need to give the manufacturers a certain patent fee. The EOL products come from the original product produced by the manufacturer. For example, CATERPILLAR has a long-term strategic partnership with many manufacturing companies that produce hydraulic pumps, hydraulic pumps, fuel pumps, oil pumps, pumps and engine components, including CATERPILLAR (Shanghai) and China's Liugong signed a long-term cooperation.

M: manufactures; Re: remanufactures.

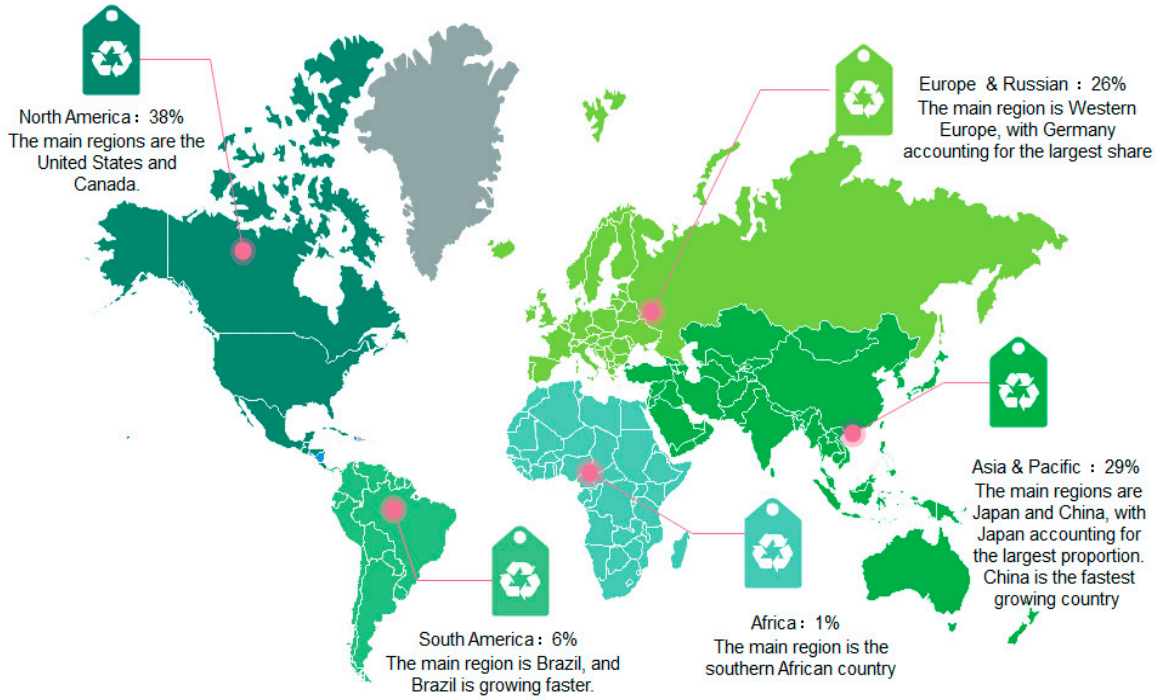

Figure 3. Distribution of world remanufacturing companies.

The E-CLSCN with original manufacturers (hereinafter referred to as the "Manufacturers"). Third-party remanufacturers (hereinafter referred to as the "Remanufacturers") and demand markets. This paper is built by M manufacturers, R remanufacturers, D demand markets, and T planning periods. Considering the situation of multi-period, the inventory is considered by this paper. The structure of the multi-period E-CLSCN is shown in Figure 4. The manufacturers that own patent rights to the NP item, take advantage of its proprietary rights to authorize the work to the remanufacturers. However, the manufacturers do not engage in the collection and remanufacture of EOL products, and there are many similar cases in the manufacturing industry, such as engine remanufacturing and hydraulic pump remanufacturing [4]. The remanufacturers engage in the EOL products collection and remanufacturing. Moreover, the remanufacturers pay the patent fee to manufacturers. It will be sued for both a tort liability and a breach of contract if the remanufacturer involves in remanufacture of patented products without paying for a patent licensing fee. For example, "Cotton-Tie Co. v. Simmons" and "Sandvik Aktiebolag v. E.J. Co." are good cases in point [4]. Manufacturers and remanufacturers retail NP and RP to demand markets through e-channel. Moreover, they use the AI-push of e-channel to promote products' sales.

Assumption 1. *All the players in the multi-period E-CLSCN are rational and they pursue the maximization of their utility [4,22,23].*

Assumption 2. *The manufacturers use raw materials to produce NP at each period, and remanufacturers collect the EOL products from demand markets at the end of each period, the EOL products are used for remanufacturing the RP at the next period [4,48].*

Assumption 3. *The consumers have preferences over the NP and RP. Manufacturers and remanufacturers retail NP and RP to demand markets through e-channel. Moreover, they use the AI-push of e-channel to promote products' sales.*

Assumption 4. *The functions involved in the model are all continuous differentiable convex functions [22,23,48]. The superscript variables with the sign of "*" in the paper are optimal values.*

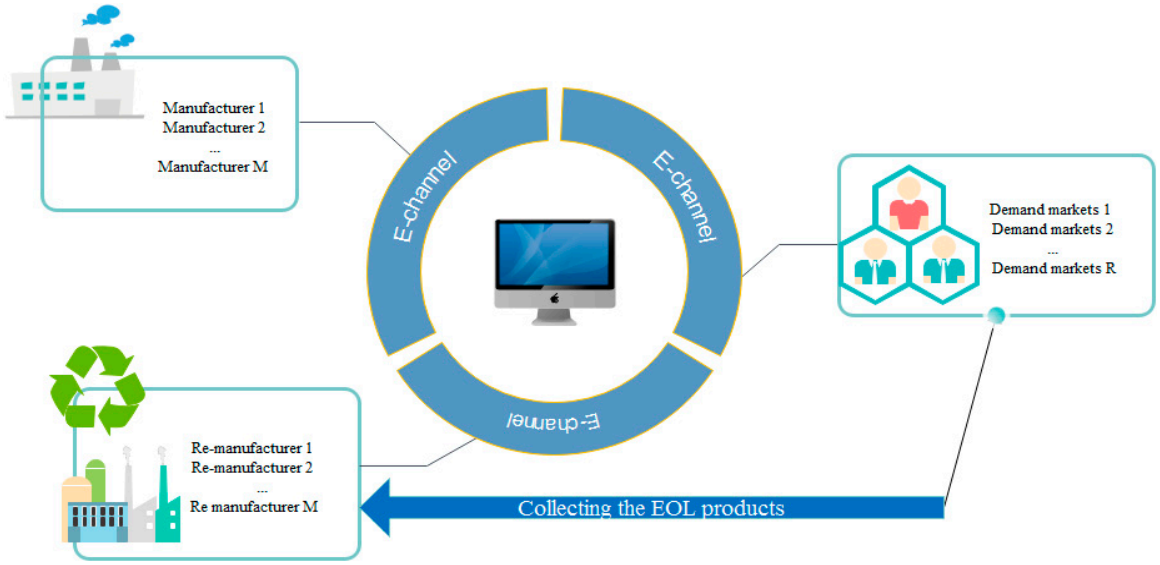

Figure 4. The closed-loop supply chain network of electronic channels (E-CLSCN) structure diagram.

3.2. The Problem Statement and Related Assumptions

Here in Table 3, the complete sign and definition of variables used in this study.

Table 3. Sign and variable definition in multi-period E-CLSCN.

Sign	Definition
Basic parameters in the E-CLSCN	
m	A typical manufacturer, $m = 1, 2, \ldots$ M
r	A typical remanufacturer, $r = 1, 2, \ldots$ R
d	A typical demand market, $d = 1, 2, \ldots$ D
t	A typical planning period, $t = 1, 2, \ldots$ T
δ	The subsidy of collect EOL products per unit that the government provides r
$v_m(t)$	The consumers' preference for NP at the t
$v_r(t)$	The consumers' preference for RP at the t
u_m	The utilization of raw materials into NP, $u_m \in [0, 1]$
u_r	The utilization of EOL products into RP, $u_r \in [0, 1]$
Transactions and production variables associated with various players in the network	
$q_m(t)$	The number of raw materials by the m at the t, all $q_m(t) = Q^{MT} \in R_+^{MT}$
$q_{md}(t)$	The number of NP sold by the m to the d at the t, all $q_{md}(t) = Q^{MDT} \in R_+^{MDT}$
$q_{rd}(t)$	The number of RP sold by the r to the d at the t, all $q_{rd}(t) = Q^{RD(T-1)} \in R_+^{RD(T-1)}$
$q_{rd}^h(t)$	The number of EOL products collected by r from d at the t, all $q_{rd}^h(t) = Q^{RD(T-1)} = R_+^{RD(T-1)}$
$w_m(t)$	The available inventory of m at the beginning of the t, all $w_m(t) = W^{MT} \in R_+^{MT}$
$w_r(t)$	The available inventory of r at the beginning of the t, all $w_r(t) = W^{R(T-1)} \in R_+^{R(T-1)}$
$p_{md}(t)$	The retail price of the NP at the t
$p_{rd}(t)$	The retail price of the RP at the t
$p_{rd}^h(t)$	The collecting price of the EOL products that the r from the d at the t

Table 3. *Cont.*

Sign	Definition
Functions associated with various players in the network	
$c_m(q_m(t))$	The function of raw materials cost, which the m Purchase at the t
$\beta_m(t)$	The cost of per unit NP's AI-push at the t
$\beta_r(t)$	The cost of per unit RP's AI-push at the t
$c_m^m(u_m, q_m(t))$	The function of the production cost of the m at the t
$c_r^r(u_r, q_{rd}^h(t))$	The function of remanufacturing cost of the r at the t
$c_{md}^z(q_{md}(t))$	The function of delayed payment cost, which the m allows the consumers to delay payment for NP
$c_{rd}^z(q_{rd}(t))$	The function of delayed payment cost, which the r allows the consumers to delay payment for RP
$I_m(w_m(t))$	The inventory cost function of the m at the t
$I_r(w_r(t))$	the inventory cost function of the r at the t
$c_{md}^m(q_{md}(t))$	The transaction costs of m and d at the t
$c_{rd}^r(q_{rd}(t))$	The transaction costs of r and d at the t
$c_{mr}(q_{rd}^h(t))$	The function of patent cost, which the m received from the r at the t.
$q_d^m(t)$	The demand function of d for NP at t, and it is randomly positively correlated with $p_{md}(t)$, $v_m(t)$ and $\beta_m(t)$, and is randomly negatively correlated with $p_{rd}(t)$. $q_d^m(t) = q_d^m(v_m(t), \beta_m(t), p_{md}(t), p_{rd}(t))$
$q_d^r(t)$	The demand function of d for RP at t, and it is randomly positively correlated with, $v_r(t)$ and $\beta_r(t)$, and is randomly negatively correlated with $p_{md}(t)$. $q_d^r(t) = q_d^r(v_r(t), \beta_r(t), p_{rd}(t), p_{md}(t))$
$V_{rd}(t)$	The negative utility function for d that sells r EOL products at t
π_i	The profits of i, $i = m, r, s, d$

4. Model Establishment

In this section, discussion of the optimal behavior of players in the multi-period E-CLSCN, and the equilibrium condition of the model is obtained by the variational inequality [22,23,48]. The consumers' preferences for products and the AI-push for products determine the demand for products. It also affects the decision-making of upper-tier players in the E-CLSCN. The research in this section lays the model foundation for the analysis of numerical examples in the next section.

4.1. Optimal Behavior and Equilibrium of Manufacturers

At the beginning of each period, the NP is retailed to demand markets by manufacturers through the e-channel, and manufacturers need to pay a certain fee of AI-push to the e-channel platform. Manufacturers manage their inventory according to the consumers' demand for NP. Manufacturers charge the patent fee from the remanufacturers. According to the problem statement and assumptions, the profit of the manufacturer is equal to the income minus the cost, where the income includes revenues from NP's retail to demand markets and patent fees from remanufacturers. The cost includes the purchase cost of raw materials, the costs of the transaction, the costs of NP's production, the cost of inventory and the cost of delayed payment by consumers. Moreover, the target of each manufacturer is to maximize their profits. The objective function of manufacturer m is as follows:

$$\max \pi_m = \sum_{t=1}^{T} \left\{ \sum_{d=1}^{D} \left[\begin{array}{c} p_{md}(t) q_{md}(t) - c_{md}^m(q_{md}(t)) \\ -c_{md}^z(q_{md}(t)) + \sum_{r=1}^{R} c_{mr}(q_{rd}^h(t)) \end{array} \right] - c_m^m(u_m, q_m(t)) - \beta_m(t) u_m q_m(t) - I_m(w_m(t)) - c_m(q_m(t)) \right\} \quad (1)$$

$$\text{s.t. } w_m(t) + u_m q_m(t+1) = w_m(t+1) + \sum_{d=1}^{D} q_{md}(t+1) \tag{2}$$

The constraint (2) denotes the inventory constraint of manufacturer m. Set $\lambda_m(t)$ as the corresponding Lagrange multiplier of the constraint (2), $\sum_{t=1}^{T}\sum_{m=1}^{M}\lambda_m(t) = \lambda^{MT} \in R_+^{MT}$, according to the assumption, which is the functions involved in the model are all continuous differentiable convex functions. Therefore, the equilibrium of manufacturers with non-cooperative games should satisfy the following variational inequalities.

Property 1. *The optimal behaviors of manufacturers could ensure* $(Q^{MT*}, Q^{MDT*}, W^{MT*}Q^{RD(T-1)}, \lambda^{MT*}) \in \Omega^M$ satisfied:

$$\begin{aligned}
&\max\pi_m = \sum_{t=1}^{T}\sum_{m=1}^{M}\left[\frac{\partial c_m^m(u_m, q_m^*(t))}{\partial q_m(t)} + \frac{\partial c_m(q_m^*(t)}{\partial q_m(t)} + \beta_m(t)u_m + u_m\lambda_m^*(t)\right] \times \left[q_m(t) - q_m^*(t)\right] \\
&+ \sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{d=1}^{D}\left[\frac{\partial c_{md}^m(q_{md}^*(t))}{\partial q_{md}(t)} + \frac{\partial c_{md}^z(q_{md}^*(t))}{q_{md}(t)} - p_{md}^*(t) - \lambda_m^*(t)\right] \times \left[q_{md}(t) - q_{md}^*(t)\right] \\
&+ \sum_{t=1}^{T-1}\sum_{m=1}^{M}\sum_{d=1}^{D}\sum_{r=1}^{R}\left[-\frac{\partial c_{mr}(q_{rd}^{h*}(t))}{\partial q_{rd}(t)}\right] \times \left[q_{rd}^h(t) - q_{rd}^{h*}(t)\right] + \sum_{t=1}^{T}\sum_{m=1}^{M}\left[\frac{\partial I_m(w_m^*(t))}{w_m(t)} + \lambda_m^*(t) - \lambda_m^*(t+1)\right] \times \left[w_m(t) - w_m^*(t)\right] \\
&+ \sum_{t=1}^{T}\sum_{m=1}^{M}\left[w_m^*(t+1) + \sum_{d=1}^{D} q_{md}^*(t+1) - w_m^*(t) - u_m q_m^*(t+1)\right] \times \left[\lambda_m(t) - \lambda_m^*(t)\right] \geq 0 \\
&\forall (Q^{MT}, Q^{MDT}, Q^{RD(T-1)}, W^{MT}, \lambda^{MT}) \in \Omega^M, \Omega^M = R_+^{3MT+MST+RD(T-1)}
\end{aligned}$$

The economic explanations of Property 1:

When $q_{md}(t) > 0$ it means the number of NP that manufacturer m is willing to retail the NP to demand market d through the e-channel is above zero, then $p_{md}^*(t) = \partial c_{md}^m(q_{md}^*(t))/\partial q_{md}(t) + \partial c_{md}^z(q_{md}^*(t))/\partial q_{md}(t) - \lambda_m^*(t)$. Here, $p_{md}^*(t)$ represents marginal profit, and $\partial c_{md}^m(q_{md}^*(t))/\partial q_{md}(t) + \partial c_{md}^z(q_{md}^*(t))/\partial q_{md}(t) - \lambda_m^*(t)$ represents marginal cost.

The implications of Property 1:

If $q_{md}(t) > 0$, then the price of NP $p_{md}^*(t)$ that the manufacturer m retail to the demand market d is endogenously determined by $p_{md}^*(t) = \partial c_{md}^m(q_{md}^*(t))/\partial q_{md}(t) + \partial c_{md}^z(q_{md}^*(t))/\partial q_{md}(t) - \lambda_m^*(t) = 0$. Thus, the retail price of the NP is equal to the sum of the marginal transaction cost and the marginal delayed payment cost minus $\lambda_m^*(t)$, which ensure the manufacturers' production and sales. In addition, when the marginal patient cost charged by the manufacturers is zero, the manufacturers are in the best interest. If the variation of the amount collected by the remanufacturers is greater than the variation of the patent costs paid by the remanufacturers, the manufacturers will not grant the production patent to the remanufacturers.

The equilibrium of Property 1:

According to the variational inequality Property 1, the formula $\frac{1}{u_m}\left(\frac{\partial c_m^m(u_m, q_m^*(t))}{\partial q_m(t)} + \frac{\partial c_m(q_m^*(t)}{\partial q_m(t)}\right) - \frac{\partial I_m(w_m^*(t))}{w_m(t)} + \beta_m(t) = p_{md}^*(t+1) - \frac{\partial c_{md}^m(q_{md}^*(t+1))}{\partial q_{md}(t+1)} - \frac{\partial c_{md}^z(q_{md}^*(t+1))}{q_{md}(t+1)}$ is achieved. Therefore, the manufacturers' investment of NP's AI-push is correlated with the retail price of NP, that is, if the manufacturers' investment of NP's AI-push is higher, the retail price of NP will increase.

4.2. Optimal Behavior and Equilibrium of Remanufacturers

The collecting of EOL products begins at the end of the first period, so the RP exists in the market from the second period ($t \geq 2$). According to Assumption 1, all the remanufacturers are rational and they pursue the maximization of their utility, thus the remanufacturers studied in the model will not have a behavior of collecting at the final period [48], such as the EOL products collected by the social organizations or the government in the final period. The remanufacturers collect EOL products from demand markets at the end of each period ($1 \leq t \leq T-1$), and the EOL products are used for remanufacturing in the next period. Remanufacturers manage their inventory according to the

consumers' demand for RP. The remanufacturers pay the patent fees to manufacturers. According to the problem statement and assumptions, the profit of the remanufacturer is equal to the income minus the cost, where income includes revenues from RP's retail to demand markets and the subsidy of collecting the EOL products. The cost includes the cost of patent fees, the costs of the transaction, the costs of RP's production, the cost of inventory and the cost of delayed payment by consumers. Moreover, the target of each remanufacturer is to maximize their profits. The objective function of remanufacturer r is as follows:

$$\begin{aligned}\max\pi_r \quad &= \sum_{t=2}^{T}\left\{\sum_{d=1}^{D}\left[p_{rd}(t)q_{rd}(t)-c^r_{rd}(q_{rd}(t))-c^z_{rd}(q_{rd}(t))\right]-c^r_r(u_r,q_r(t))-I_r(w_r(t))-\beta_r(t)u_rq^h_r(t-1)\right\}\\ &+\sum_{t=1}^{T-1}\sum_{d=1}^{D}\left[\delta q^h_{rd}(t)-q^h_{rd}(t)p^h_{rd}(t)-\sum_{m=1}^{M}c_{mr}(q^h_{rd}(t))\right]\end{aligned} \tag{3}$$

$$\text{s.t. } w_r(t)+u_rq^h_{rd}(t)=w_r(t+1)+\sum_{d=1}^{D}q_{rd}(t+1) \tag{4}$$

The constraint (4) denotes the inventory constraint of remanufacturer r. Set $\tau_r(t)$ as the corresponding Lagrange multiplier of the constraint (4), $\sum_{t=1}^{T-1}\sum_{r=1}^{R}\tau_r(t)=\tau^{R(T-1)}\in R_+^{R(T-1)}$. According to the assumption, which is the functions involved in the model are all continuous differentiable convex functions. Therefore, the equilibrium of remanufacturers with non-cooperative games should satisfy the following variational inequalities.

Property 2. *The optimal behaviors of all remanufacturers could ensure* $\forall(Q^{RD(T-1)*},Q_H^{RD(T-1)*},W^{R(T-1)*},\tau^{R(T-1)*})\in\Omega^R$ satisfied:

$$\begin{aligned}&\sum_{t=2}^{T}\sum_{r=1}^{R}\sum_{d=1}^{D}\left[\frac{\partial c^r_{rd}(q^*_{rd}(t))}{\partial q_{rd}(t)}+\frac{\partial c^z_{rd}(q^*_{rd}(t))}{\partial q_{rd}(t)}-p^*_{rd}(t)-\tau^*_r(t)\right]\times\left[q_{rd}(t)-q^*_{rd}(t)\right]\\ &\sum_{d=1}^{D}\sum_{r=1}^{R}\left[\sum_{t=1}^{T-1}\left[p^{h*}_{rd}(t)-\delta+\sum_{m=1}^{M}\frac{c_{mr}(q^{h*}_{rd}(t))}{\partial q^h_{rd}(t)}-u_r\tau^*_r(t)+u_r\beta_r(t)\right]+\sum_{t=2}^{T}\frac{\partial c^r_r(u_r,q^{h*}_{rd}(t-1))}{\partial q^h_{rd}(t)}\right]\times\left[q^h_{rd}(t)-q^{h*}_{rd}(t)\right]\\ &+\sum_{t=2}^{T}\sum_{r=1}^{R}\left[\frac{\partial I_r(w^*_r(t))}{\partial w_r(t)}+\tau^*_r(t)-\tau^*_r(t+1)\right]\times\left[w_r(t)-w^*_r(t)\right]\\ &+\sum_{t=2}^{T}\sum_{r=1}^{R}\left[w_r(t+1)+\sum_{d=1}^{D}q_{rd}(t+1)-w_r(t)-u_rq^{h*}_r(t)\right]\times\left[\tau_r(t)-\tau^*_r(t)\right]\geq 0\\ &\forall(Q^{RD(T-1)},Q_H^{RD(T-1)*},W^{R(T-1)},\tau^{R(T-1)})\in\Omega^R,\Omega^R=R_+^{2R(DT+T-D-1)}\end{aligned}$$

The economic explanations of Property 2:

When $q_{rd}(t)>0$ it means the number of RP that remanufacturer r is willing to retail the RP to demand market d through the e-channel is above zero, then $p^*_{rd}(t)=\partial c^r_{rd}(q^*_{rd}(t))/\partial q_{rd}(t)+\partial c^z_{rd}(q^*_{rd}(t))/\partial q_{rd}(t)-\tau^*_r(t)$. Here, $p^*_{rd}(t)$ represents marginal profit, and $\partial c^r_{rd}(q^*_{rd}(t))/\partial q_{rd}(t)+\partial c^z_{rd}(q^*_{rd}(t))/\partial q_{rd}(t)-\tau^*_r(t)$ represents marginal cost.

The implications of Property 2:

If $q_{rd}(t)>0$, then the price of RP $p^*_{rd}(t)$ that the remanufacturer r retail to the demand market d is endogenously determined by $p^*_{rd}(t)-\partial c^r_{rd}(q^*_{rd}(t))/\partial q_{rd}(t)-\partial c^z_{rd}(q^*_{rd}(t))/\partial q_{rd}(t)+\tau^*_r(t)=0$. Thus, the sales price of the RP is equal to the sum of the marginal transaction cost and the marginal delayed payment cost minus $\tau^*_r(t)$, which ensure the remanufacturers' collecting and remanufacturing.

The equilibrium of Property 2:

According to the variational inequality Property 2, the formula $\frac{c_{mr}(q^{h*}_{rd}(t))}{\partial q^h_{rd}(t)}+p^{h*}_{rd}(t)-\delta+u_r\beta_r(t)=u_r[p^*_{rd}(t+1)-\frac{\partial c^r_{rd}(q^*_{rd}(t+1))}{\partial q_{rd}(t)}-\frac{\partial c^z_{rd}(q^*_{rd}(t+1))}{\partial q_{rd}(t)}]-\frac{\partial c^r_r(u_r,q^*_r(t+1))}{\partial q_r(t)}$ is achieved. Therefore, the remanufacturer'

investment of RP's AI-push is correlated with the retail price of RP, that is, if the remanufacturer' investment of RP's AI-push is higher, the retail price of RP will increase.

4.3. Optimal Behavior and Equilibrium of Demand Markets

The consumers' demand for products can be satisfied by purchasing NP or RP, and they have a preference for products (NP and RP). In addition, their decisions to purchase NP or RP are influenced by AI-push. According to the previous assumptions, the following is stated.

$$q_d^m(t) = \begin{cases} \sum_{m=1}^{M} q_{md}^*(t), p_{md}^{m*}(t) > 0 \\ \sum_{m=1}^{M} q_{md}^*(t), p_{md}^{m*}(t) = 0 \end{cases} \tag{5}$$

$$q_d^r(t) = \begin{cases} \sum_{r=1}^{R} q_{rd}^*(t), p_{rd}^{r*}(t) > 0 \\ \sum_{r=1}^{R} q_{rd}^*(t), p_{rd}^{r*}(t) = 0 \end{cases} \tag{6}$$

where $\begin{cases} q_d^r(t) = q_d^r(v_r(t), \beta_r(t), p_{rd}(t), p_{md}(t)) \\ q_d^m(t) = q_d^m(v_m(t), \beta_m(t), p_{md}(t), p_{rd}(t)) \end{cases}$.

For consumers, recycling of EOL products by remanufacturers' will inevitably cause some inconvenience, means negative utilities for consumers. It relates to the number of collecting EOL products $V_{rd}^*(t) = V_{rd}^*(Q^{RD}(t)), Q^{RD}(t) = \sum_{t=1}^{T} \sum_{d=1}^{D} q_{rd}^h(t)$. The compensation will need to be given to the consumers by remanufacturers, which mainly reflects the price [48]. The number of EOL products collected by remanufactures cannot exceed the able-collected EOL products in the demand markets.

$$V_{rd}^*(t) = \begin{cases} p_{rd}^{h*}(t), q_{rd}^{h*}(t) > 0 \\ p_{rd}^{h*}(t), q_{rd}^{h*}(t) = 0 \end{cases} \tag{7}$$

$$\text{s.t.} \sum_{r=1}^{R} q_{rd}^{h*}(t) \le \sum_{m=1}^{M} q_{md}^*(t) + \sum_{r=1}^{R} q_{rd}^*(t) \tag{8}$$

The constraint (8) denotes the constraint of able-collected EOL products of remanufacturer r. Set $\eta_d(t)$ as the corresponding Lagrange multiplier of the constraint (8), $\sum_{t=1}^{T-1} \sum_{d=1}^{D} \eta_d(t) = \eta^{D(T-1)} \in R_+^{D(T-1)}$, if (5)–(8) are simultaneously satisfied, achieve the following variational inequalities.

Property 3. *The optimal behaviors of demand markets could ensure* $(P^{MDT*}, P^{RD(T-1)*}, Q_H^{RD(T-1)*}, \eta^{D(T-1)*}) \in \Omega^D$ *satisfied:*

According to Property 3, achieve (9),

$$\begin{cases} q_{md}^*(t) + q_{rd}^*(t) - q_{rd}^{h*}(t) = 0 \\ V_{vd}(t) - p_{rd}^{h*}(t) + \eta_d^*(t) = 0 \end{cases} \tag{9}$$

According to the actual situation of markets, the collecting is incomplete, so item 1 of (9) is not established, and item 2 of (9) will be brought into equilibrium. Therefore, the economic explanation for the collection trading conditions is that the collecting price of EOL products is equal to the negative utility of consumers, and reverse transactions will occur in the multi-period E-CLSCN.

4.4. Multi-Period E-CLSCN Equilibrium Model

The similar level players have a competing relationship with each other, and the upper-lower players have a supply-demand relationship with each other. The multi-period E-CLSCN reaches an equilibrium when transactions between players are an initiative by all manufacturers, remanufacturers and demand markets.

- The number of NP, which manufacturers are willing to retail the demand markets, is equal to the number of NP that the demand markets are willing to buy. The number of RP between remanufacturers and demand markets has the same trend.
- The price of the NP, which the retail price of manufacturers is the same as the price of consumers are willing to pay. The price of RP between remanufacturers and demand markets has the same trend.
- The price of the EOL products, which the collecting price of remanufacturers is equal to the negative utility of consumers.

Therefore, the multi-period E-CLSCN needs to simultaneously satisfy Properties 1–3, that is to say, manufacturers, remanufacturers and demand markets synchronously reach an equilibrium. Achieve the following variational inequalities.

Property 4. *The Nash equilibrium condition of multi-period E-CLSCN could ensure* $\forall(Q^{MT*}, Q^{MDT*}, Q_H^{RD(T-1)*}, Q^{R(T-1)*}, Q^{RD(T-1)*}, W^{MT*}, W^{R(T-1)*} P^{MDT*}, P^{RD(T-1)*}, \lambda^{MT*}, \tau^{R(T-1)*}, \eta^{D(T-1)*}) \in \Omega$ satisfied:

$$\sum_{t=1}^{T}\sum_{m=1}^{M}\left[\frac{\partial c_m^m(u_m,q_m^*(t))}{\partial q_m(t)} + \frac{\partial c_m(q_m^*(t)}{\partial q_m(t)} + \beta_m u_m + u_m\lambda_m^*(t)\right]\times[q_m(t)-q_m^*(t)]$$
$$+\sum_{t=1}^{T}\sum_{m=1}^{M}\sum_{d=1}^{D}[\frac{\partial c_{md}^m(q_{md}^*(t))}{\partial q_{md}(t)} + \frac{\partial c_{md}^z(q_{md}^*(t))}{q_{md}(t)} - p_{md}^{m*}(t) - \lambda_m^*(t)\Bigg]\times\Big[q_{md}(t)-q_{md}^*(t)\Big]$$
$$\sum_{r=1}^{R}\sum_{d=1}^{D}\left[\sum_{t=1}^{T-1}\left[V_{vd}(q_{rd}^{h*}(t)) + \eta_d^*(t) - \delta + \sum_{m=1}^{M}\frac{c_{mr}(q_{rd}^{h*}(t))}{\partial q_{rd}^h(t)} - u_r\tau_r^*(t) + \beta_r u_r\right] + \sum_{t=2}^{T}\frac{\partial c_r^r(u_r,q_{rd}^{h*}(t-1))}{\partial q_{rd}^h(t)}\right]\times\Big[q_{rd}^h(t)-q_{rd}^{h*}(t)\Big]$$
$$+\sum_{t=2}^{T}\sum_{r=1}^{R}\sum_{d=1}^{D}\left[-p_{rd}^{r*}(t) + \frac{\partial c_{rd}^r(q_{rd}^*(t))}{\partial q_{rd}(t)} + \frac{\partial c_{rd}^z(q_{rd}^*(t))}{\partial q_{rd}(t)} - \tau_r^*(t)\right]\times\Big[q_{rd}(t)-q_{rd}^*(t)\Big]$$
$$+\sum_{t=1}^{T}\sum_{m=1}^{M}\left[\frac{\partial I_m(w_m^*(t))}{w_m(t)} + \lambda_m^*(t) - \lambda_m^*(t+1)\right]\times[w_m(t)-w_m^*(t)] + \sum_{t=2}^{T}\sum_{r=1}^{R}\left[\frac{\partial I_r(w_r^*(t))}{\partial w_r(t)} + \tau_r^*(t) - \tau_r^*(t+1)\right]\times[w_r(t)-w_r^*(t)]$$
$$+\sum_{t=1}^{T}\sum_{d=1}^{D}\left[\sum_{m=1}^{M}q_{md}^*(t) - q_d^{m*}(t)\right]\times\Big[p_{md}(t)-p_{md}^*(t)\Big] + \sum_{t=2}^{T}\sum_{d=1}^{D}\left[\sum_{r=1}^{R}q_{rd}^*(t) - q_d^{r*}(t)\right]\times\Big[p_{rd}(t)-p_{rd}^*(t)\Big]$$
$$+\sum_{t=1}^{T}\sum_{m=1}^{M}\left[w_m^*(t+1) + \sum_{d=1}^{D}q_{md}^*(t+1) - w_m^*(t) - u_m q_m^*(t+1)\right]\times[\lambda_m(t)-\lambda_m^*(t)]$$
$$+\sum_{t=2}^{T}\sum_{r=1}^{R}\left[w_r(t+1) + \sum_{d=1}^{D}q_{rd}(t+1) - w_r(t) - u_r q_{rd}^h(t)\right]\times[\tau_r(t)-\tau_r^*(t)]$$
$$+\sum_{t=1}^{T-1}\sum_{d=1}^{D}\left[\sum_{m-1}^{M}q_{md}^*(t) + \sum_{r=1}^{R}q_{rd}^*(t) - \sum_{r=1}^{R}q_{rd}^{h*}(t)\right]\times\Big[\eta_d(t)-\eta_d^*(t)\Big]\geq 0$$
$$\forall(Q^{MT}, Q^{MDT}, Q_H^{RD(T-1)}, Q^{R(T-1)}, Q^{RD(T-1)}, W^{MT}, W^{R(T-1)}, P^{MDT}, P^{RD(T-1)}, \lambda^{MT}, \tau^{R(T-1)}, \eta^{D(T-1)}) \in \Omega$$
$$\Omega = \Omega^M \times \Omega^R \times \Omega^D$$

Property 5. *According to Property 4, the collecting price of EOL products is the Endogenous variable. Through properties 2 and properties 4, the formula* $p_{rd}^{h*}(t) = u_r\tau_r(t) + \delta - u_r\beta_t(t) - \frac{\partial c_{mr}(q_{rd}^{h*}(t))}{\partial q_{rd}^h(t)} - \frac{\partial c_r^r(u_r,q_{rd}^{h*}(t))}{\partial q_{rd}^h(t)} = V_{rd}^*(t) + \eta_d^*(t)$ *is achieved.*

Therefore, the collecting price of EOL products is negatively correlated to the cost of remanufacturer's AI-push, the marginal patent cost, and the marginal remanufactured product

production cost, however, it is positively correlated to the consumers' negative utility. So, for remanufacturers, in the process of recycling for EOL products, if the remanufacturers want to reduce the collecting price, remanufacturers need to take measures to reduce the troubles caused by collecting the EOL products from demand markets.

5. Numerical Examples

In this section, in order to analyze the impact of consumers' preferences for products and the AI-push on the equilibrium of multi-period E-CLSCN, this study provides some numerical examples to illustrate the model and discuss the results. We assume two manufacturers, two remanufacturers and two demand markets in the 5-period E-CLSCN. The structure of the E-CLSCN is shown in Figure 5. The functions referred to in this paper are shown in Table 4, and the functions are similar to Nagurney et al. [22], Tao et al. [48] and Wang et al. [23]. This paper adopts the modified projection contraction algorithm to solve the model, and MATLAB is used for programming [22,23,48]. The numerical examples focus on analyzing and discussing the following issues.

1. When the consumers' preference for products and the manufacturers'(remanufacturers') AI-push are static at planning periods, this paper compares and analyze the profits of manufacturers, remanufacturers and whole E-CLSCN.
2. The consumers' preference for products and the manufacturers'(remanufacturers') AI-push are dynamic at planning periods, this paper compares and analyze the profits of manufacturers, remanufacturers and whole E-CLSCN.

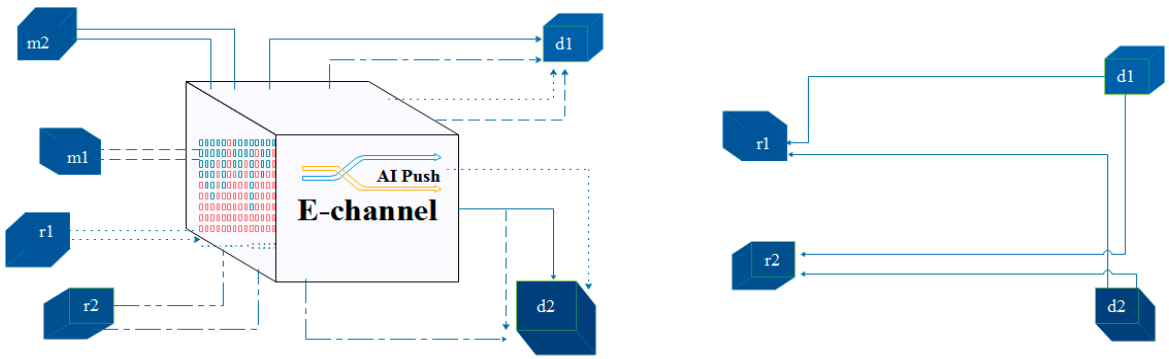

Figure 5. The structure of the E-CLSCN.

Table 4. The structure of the E-CLSCN.

Cost	Function
The function of raw materials cost at the t	$c_m(t) = c_m(q_m(t)) = (2+t)(q_m(t))^2 + q_m(t) + 1$
The function of the production cost of the m at the t	$c_m^m(u_m, q_m(t)) = (2+0.5t)(u_m q_m(t))^2 + u_m q_m(t) + 1$
The function of remanufacturing cost of the r at the t	$c_r^r(u_r, q_r^h(t)) = (1.5-0.25t)u_r q_r^h(t) + u_r q_r^h(t) + 2$
The function of delayed payment cost at the t	$c_{id}^z(q_{id}(t)) = \{\beta_i q_{id}(t) \vert i = m, r\}$
The inventory cost function of the player at the t	$I_i(t) = \{(1+0.25t)w_i(t) \vert i = m, r\}$
The transaction costs of m/r and d at the t	$c_{id}^i(t) = \left\{q_{id}(t)^2 + 2q_{id}(t) + 1 \vert i = m, r\right\}$
The function of patent cost at the t	$c_{mr}(t) = 0.15 q_{rd}^h(t)$
The demand function of d for NP in the first period	$q_{d_i}^m(1) = -2.5 p_{m_1 d_i}^m(1) - (1.5-0.2)p_{m_2 d_i}^m(1) + 400(\beta_m(1) + 100 v_m(1))$
The demand function of d for NP at t	$q_{d_i}^m(t) = -2.5 p_{m_1 d_i}^m(t) - (1.5-0.2t)p_{m_2 d_i}^m(t) + 0.1(p_{r_1 d_i}^r(t) + p_{r_2 d_i}^r(t)) + (400-10t)(\beta_m(t) + 100 v_m(t)) - (50-2t)\beta_r(t)$
The demand function of d for RP at t	$q_{d_i}^r(t) = -1.5 p_{r_1 d_i}^r(t) - (1-0.1t)p_{r_2 d_i}^r(t) + 0.15(p_{m_1 d_i}^m(t) + p_{m_2 d_i}^m(t)) + (200-10t)(\beta_r(t) + 100 v_r(t)) - (25-2t)\beta_m(t)$
The negative utility function for d thatsells r EOL products at t	$V_{rd}(t) = 0.45(\sum_{r=1}^{2}\sum_{d=1}^{2} q_{rd}^h(t)) + 2$

5.1. Numerical Example 1

When the consumers' preference for products and the manufacturers'(remanufacturers') AI-push are static at planning periods, this section compares and analyze the profits of manufacturers, remanufacturers and whole CLSCN, where $u_m = 0.98, u_r = 0.90, \delta = 0.15$. The results are shown in Figure 6.

Conclusion 1. *When the $v_m(t)$ is increasing, it is beneficial to the profits of manufacturers and the whole E-CLSCN, but it is not conducive to the profits of remanufacturer. Moreover, when the $v_r(t)$ is increasing, it is beneficial to the profits of the remanufacturer, but it is not conducive to the profits of the manufacturers and the whole E-CLSCN.*

Conclusion 2. *The impact of the manufacturer's AI-push $\beta_m(t)$ is more significant than the remanufacturers' AI-push $\beta_r(t)$ for the multi-period E-CLSCN. When the $\beta_m(t)$ is increasing, it is beneficial to the profits of manufacturers, remanufacturers and the whole E-CLSCN. However, when the $\beta_m(t)$ is fixed and the $\beta_r(t)$ is increasing, it is beneficial to the profits of remanufacturers and not conducive to the profits of manufacturers and the whole E-CLSCN.*

As seen in Figure 6, when the $\beta_m(t)$ and $\beta_r(t)$ are fixed, from the upper layer to the lower layer, the $v_m(t)$ are 0.7, 0.5 and 0.3 in Figure 6a,c, thus the $v_m(t)$ is positively correlated with the profits of manufacturers and whole E-CLSCN. However, we see that the $v_m(t)$ are 0.3, 0.5 and 0.7 in Figure 4b, thus the $v_m(t)$ is negatively correlated with the profits of remanufacturers.

The condition of the $v_m(t)$ and $v_r(t)$ are fixed, when $\beta_m(t) = 0.1$, $\beta_r(t) = 0.5$, the profits of manufacturers and the whole E-CLSCN are minimum. When $\beta_m(t) = \beta_r(t) = 0.1$, the profits of remanufacturers are minimum, and the profits of manufacturers and whole E-CLSCN are slightly higher than $\beta_m(t) = 0.1$, $\beta_r(t) = 0.5$. When $\beta_m(t) = 0.5, \beta_r(t) = 0.1$ the profits of manufacturers and the whole E-CLSCN are maximum, the profits of remanufacturers are slightly higher than $\beta_m(t) = 0.1$. When $\beta_m(t) = 0.5, \beta_r(t) = 0.5$ the profits of manufacturers are highest. We will thus explain this phenomenon that the E-CLSCN is greatly affected by manufacturers, and the manufacturers play an important role in the multi-period E-CLSCN.

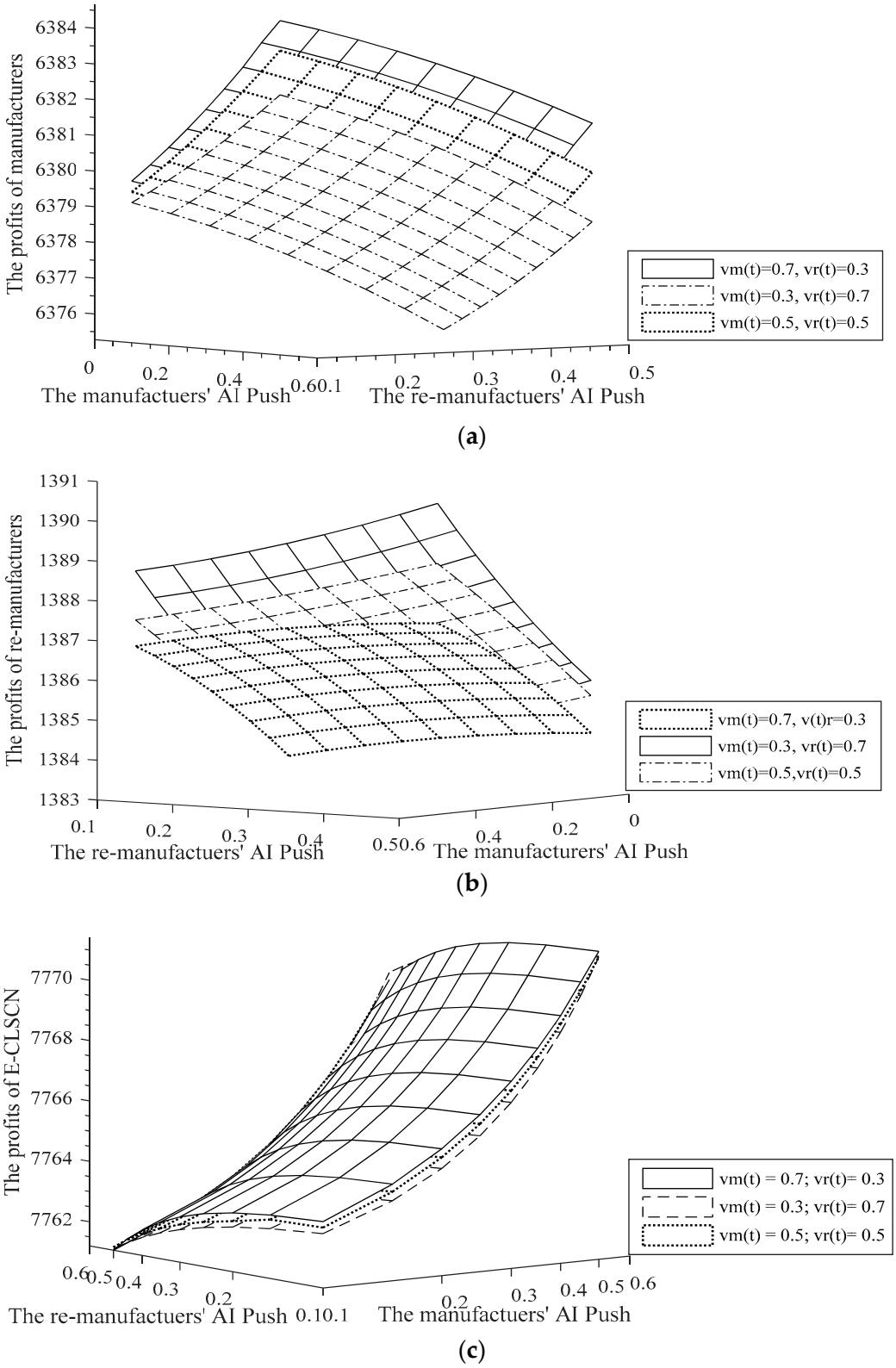

Figure 6. The profits of E-CLSCN under the static conditions.

5.2. Numerical Example 2

The consumers' preference for products and the manufacturers'(remanufacturers') AI-push are dynamic at planning periods, this section compare and analyze the profits of manufacturers, remanufacturers and whole CLSCN. Where $u_m = 0.98, u_r = 0.90, \delta = 0.15$.

In order to better analyze the impact of the dynamic situation of AI-push and consumers' preferences for products on the multi-period E-CLSCN, the change of $\beta_m(t), \beta_r(t)$ considered four situations (increasing, decreasing, increasing-decreasing and decreasing-increasing). At the same time, the $v_m(t), v_r(t)$ considered three situations (the preference of NP is higher, the preference of RP is higher and the preference of NP and RP are equal). The specific dynamic changes are shown in Table 5.

Table 5. Dynamic changes in artificial intelligence push (AI-push) and consumers' preference for products.

Symbol	Dynamic Change
p_{m1}	$\beta_m(1) = \beta_m(2) = 0.4, \beta_m(3) = 0.3, \beta_m(4) = 0.2, \beta_m(5) = 0.1$
p_{m2}	$\beta_m(1) = \beta_m(2) = 0.4, \beta_m(3) = 0.1, \beta_m(4) = 0.3, \beta_m(5) = 0.4$
p_{m3}	$\beta_m(1) = \beta_m(2) = 0.1. \beta_m(3) = 0.4, \beta_m(4) = 0.3, \beta_m(5) = 0.2$
p_{m4}	$\beta_m(1) = \beta_m(2) = 0.1, \beta_m(3) = 0.2, \beta_m(4) = 0.3, \beta_m(5) = 0.4$
p_{r1}	$\beta_r(2) = 0.4, \beta_r(3) = 0.3, \beta_r(4) = 0.2, \beta_r(5) = 0.1$
p_{r2}	$\beta_r(2) = 0.1, \beta_r(3) = 0.4, \beta_r(4) = 0.3, \beta_r(5) = 0.2$
p_{r3}	$\beta_r(2) = 0.1, \beta_r(3) = 0.2, \beta_r(4) = 0.3, \beta_r(5) = 0.4$
p_{r4}	$\beta_r(2) = 0.4, \beta_r(3) = 0.1, \beta_r(4) = 0.3, \beta_r(5) = 0.4$
v_1	$v_m(t) = 0.7, v_r(t) = 0.3, t = 1, 2...5$
v_2	$v_m(t) = 0.5, v_r(t) = 0.5, t = 1, 2...5$
v_3	$v_m(t) = 0.3, v_r(t) = 0.7, t = 1, 2...5$

Conclusion 3. *The consumers' preference for products is at the dynamic condition is similar to those in static conditions at the planning periods.*

Conclusion 4. *The manufacturers' AI-push and the remanufacturers' AI-push are higher at the preliminary planning period, which has a more obvious impact for the players in all E-CLSCN. Moreover, the impact of the manufacturers' AI-push is more significant than the remanufactures' AI-push the players in all E-CLSCN.*

Conclusion 5. *AI-push can effectively increase the profits of the manufacturers and remanufacturers, but the marginal benefits of AI-push investment gradually decrease during the planning period.*

Combined with Figure 6 and Table 6, the condition of the AI-push is dynamic, which is similar to the conditions of static. When the dynamic condition of the v_1, the profits of manufacturers and whole CLSCN are maximum, the profits of remanufacturers are minimum. When the dynamic condition is the v_3, the profits of manufacturers, remanufacturers and whole CLSCN are minimum. As seen in Figure 6, the condition of the $\beta_r(t)$ is fixed, when the $\beta_m(t)$ is dynamic, the profits of manufacturers, remanufacturers and the whole CLSCN are p_{m1}, p_{m2}, p_{m3}, p_{m4} from maximum to minimum. The condition of the $\beta_m(t)$ is fixed, when the $\beta_r(t)$ is dynamic, the profits of manufacturers and whole CLSCN are p_{m1}, p_{m2}, p_{m3}, p_{m4} from maximum to minimum, however, the profits of remanufacturers are p_{r1}, p_{r4}, p_{r2}, p_{r3} from maximum to minimum. To explain this phenomenon, when t = 1, the NP are sold on the E-CLSCN only, thus the higher AI-push for NP, the better the CLSCN. When the RP enter the demand markets $t > 1$, the AI-push for RP, it benefits the increasing the sales number of RP, thereby the profits of remanufacturers are increasing, which effectively promote the development of the remanufacturing industry. Moreover, the process of remanufacturing the RP that the remanufacturers are required to pay the patent fees for manufacturers, so the development of the remanufacturing industry can also promote the manufacturing industry.

Moreover, further compare the results of Figure 6 and Table 6, to analyze the impact of AI-push on the E-CLSCN. When the condition of the consumers' preference for products is fixed, the manufacturer's and remanufacturers' AI-push is gradually increased during the planning period, although the profits of the manufacturers and remanufacturers increased, the increase is not obvious. The sensitivity of the demand markets for the investment of manufacturers' and remanufacturers' AI-push is gradually reducing. The marginal benefit of the investment of AI-push is gradually decreasing.

Table 6. The profits of E-CLSCN situation under the dynamic conditions.

Dynamic		P_{m1}			P_{m2}		
		v_1	v_2	v_3	v_1	v_2	v_3
p_{r1}	$\sum \pi_m$	6385.2	6383.8	6381.6	6376.0	6374.9	6373.8
	$\sum \pi_r$	1384.5	1385.0	1386.4	1380.7	1381.5	1382.1
	$\sum \pi$	7769.7	7768.8	7768.0	7756.7	7756.4	7755.9
p_{r2}	$\sum \pi_m$	6384.2	6382.7	6380.4	6375.1	6372.7	6371.5
	$\sum \pi_r$	1381.1	1382.1	1383.9	1378.0	1378.6	1379.4
	$\sum \pi$	7765.3	7764.8	7764.3	7753.1	7751.3	7750.9
p_{r3}	$\sum \pi_m$	6379.4	6377.9	6376.3	6371.64	6370.1	6369.2
	$\sum \pi_r$	1380.9	1381.7	1382.5	1376.8	1377.4	1378.0
	$\sum \pi$	7760.3	7759.6	7758.8	7748.4	7747.5	7747.2
p_{r4}	$\sum \pi_m$	6376.2	6375.4	6373.8	6368.4	6367.0	6365.6
	$\sum \pi_r$	1383.2	1383.3	1384.1	1379.1	1380.1	1381.3
	$\sum \pi$	7759.4	7758.7	7757.9	7747.5	7747.1	7746.9
Dynamic		P_{m3}			P_{m4}		
		v_1	v_2	v_3	v_1	v_2	v_3
p_{r1}	$\sum \pi_m$	6368.3	6365.9	6359.9	6359.3	6358.0	6356.7
	$\sum \pi_r$	1375.1	1377.0	1377.6	1372.3	1372.9	1373.4
	$\sum \pi$	7743.4	7742.9	7737.5	7731.6	7730.9	7730.1
p_{r2}	$\sum \pi_m$	6367.7	6364.4	6363.1	6358.4	6355.2	6355.1
	$\sum \pi_r$	1373.8	1374.2	1375.1	1368.4	1370.7	1369.1
	$\sum \pi$	7741.5	7738.6	7738.2	7726.8	7725.9	7724.2
p_{r3}	$\sum \pi_m$	6362.9	6361.6	6360.3	6354.1	6352.7	6351.3
	$\sum \pi_r$	1372.9	1373.1	1373.8	1367.2	1367.8	1368.6
	$\sum \pi$	7735.8	7734.7	7734.1	7721.3	7720.5	7719.9
p_{r4}	$\sum \pi_m$	6360.0	6358.3	6356.8	6350.1	6348.5	6347.1
	$\sum \pi_r$	1374.9	1375.9	1376.8	1370.4	1371.1	1371.7
	$\sum \pi$	7734.9	7734.2	7733.6	7720.2	7719.6	7718.8

6. Discussion of Results and Managerial Insights

6.1. Discussion of Results

A comprehensive discussion of the results of Numerical Examples 1 and 2, the results shown that $v_m(t)$ have a positive correlation with manufacturers' profits and whole E-CLSCN and negatively correlated with remanufacturers, that is, the E-CLSCN is greatly influenced by manufacturers, and manufacturers occupy a dominant position in the E-CLSCN. Moreover, in the aspect of AI-push, the impact of the manufacturers' AI-push is more significant than the remanufactures' AI-push on the multi-period E-CLSCN.

Therefore, if the government want to promote the sustainable development of resources and the development of the remanufacturing industry, through the increase the consumers' preference for RP, force the manufacturers' AI-push, and increase the remanufacturers' AI-push, it is not conducive to the E-CLSCN. However, if business and government want to promote the development of the E-CLSCN, through increase consumers' preference for NP, and increase manufacturers' AI-push, it is contrary to the circular and sustainable economy and the development of the remanufacturing industry. The following managerial insights will solve the above problems through some methods.

6.2. Managerial Insights

In order to increase the sustainable utilization of resources, the development of the remanufacturing industry and the whole E-CLSCN, in this section we have put forward some interesting management inspirations from the perspective of the government and enterprises.

6.2.1. The Perspective of the Government

Government intervention can effectively promote the sustainable utilization of resources and the development of the circular economy [49]. Therefore, the government has the responsibility to take some measures to coordinate manufacturers and remanufacturers.

Firstly, considering the leader position of the manufacturers, the government's goal should be mainly to increase the profits of remanufacturers, either adding subsidies to the remanufacturers EOL product collecting or adopting subsidies to the consumers for purchase the RP. It turns out that adopting subsidies to consumers is the most effective method to promote product purchases [50]. Moreover, free publicity of RP on the government's public platform, and emphasizing the importance of RP and environmental protection, increasing consumers' preference for RP.

Secondly, while promoting the development of the remanufacturing industry, the government cannot suppress the development of manufacturers. This will reduce the E-CLSCN, which is not conducive to the development of the product, which will easily lead to the overall development of enterprises related to NP, including raw material manufacturers and so on. Therefore, the government should adopt a dynamic strategy according to the actual situation of the market.

1. When consumers' preference for RP is higher, the government should increase the minimum recovery for EOL products (increase the patent fees), reduce the subsidies for remanufacturers, and give the subsidies for manufacturers. Moreover, the government should increase subsidies for remanufacturers' AI-push, which can increase the development of E-CLSCN.
2. When the consumers' preference for NP is higher, the government should increase the subsidies for collection EOL products by remanufacturers, reduce the patent fees and subsidies for consumers to purchase the RP.

6.2.2. The Perspective of Manufacturers and Remanufacturers

For manufacturers, manufacturers are leaders in the E-CLSCN, and through the results of numerical examples, the AI-push is significant for manufacturers and the whole supply chain, so the manufacturers should increase the cost of AI-push. Manufacturers should increase their investment of AI-push and in the first planning period. Moreover, it is so important to increase their manufacturing capabilities. The conversion rate of raw materials and the product's quality are effective ways to increase consumers' preference for NP. For remanufacturers, it is so important to increase remanufacturing capabilities, the conversion rate of EOL products and the RP's quality. Since manufacturers dominate the E-CLSCN, remanufacturers can use profit-sharing mechanisms, which not only encourages manufacturers to consider the profits of remanufacturers when considering NP's AI-push, but through the profit-sharing mechanisms can benefit promote the E-CLSCN.

The manufacturers and the remanufacturers should use information technology to predict consumers' preference for products and adjust corporate strategies in time according to their conditions through forecasting results. In view of the fact that the product preferences of the early consumers have a more significant impact on the E-CLSCN, it is more important for the companies to promote the product preferences of consumers, and the appropriate advertising strategies can be used to enhance the product promotion. Moreover, enterprises should adopt dynamic AI-push investment and the dynamic marketing policies according to the dynamic products' preferences of the consumers.

In addition, manufacturers and remanufacturers should also strive to take social responsibility. Broadly speaking, the corporate social responsibility (CSR) is regularly defined as a strategy which encourages social activities management in organizations [51]. CSR proposes that firms hold responsibilities toward a broader

group of stakeholders such as customers, employees, etc. Recent empirical evidence demonstrates that customers are willing to pay a higher price for goods with CSR attributes and CSR programs influence 70% of all consumer purchasing decisions [51], so it is necessary to consider the CSR on the E-CLSCN. For manufacturers and remanufacturers, in order to increase their own profits, it is necessary to implement products' information and AI-push for recycling information. When a company has a strong consumer awareness, the more active the company is in terms of social responsibility, the higher its value. Whether a company considers the CSR or not will have a significant impact on consumers' choice of their products. Therefore, this paper recommends that manufacturers and remanufacturers actively engage in conducting dynamic AI-push. Meanwhile, CSR is considered.

7. Conclusions, Limitations and Future Direction

7.1. Conclusions

The remanufacturing industry means the transformation of human industrial civilization. Its economic and management concepts are economic, green, and sustainable development. Moreover, remanufacturing has become an indispensable part of industrial civilization, and the E-CLSCN, which combines forward logistics and reverse logistics, is in line with this development. Therefore, the E-CLSCN, which combines forward logistics and reverse logistics, has a significant contribution to resource conservation and sustainable development. This paper studies E-CLSCN equilibrium. This paper considers the influence of consumers' preference for products and AI-push on the equilibrium results. The E-CLSCN model is constructed by using variational inequalities, and the sensitivity analysis is carried out by numerical examples. The conclusions of this paper are similar to the study of Zhao et al. [12], that is, consumers' preference for products can effectively promote the profits of the corresponding node enterprises. However, this paper considers complex dynamic and static problems, so the results of this paper are more abundant than the study of Zhao et al. [12]. The conclusions and management implications of this study are as follows:

The impact of research results on the economic performance of enterprises:

(1) The consumers' preference for products and AI-push are factors that can effectively promote the profits of the corresponding companies. However, they have different effects on the equilibrium results on dynamic issues. (2) The condition of the consumers' preference for products and the AI-push are static. When the consumers' preference for NP is at a higher level, the profits of the manufacturers and the whole E-CLSCN are higher. At the same time, the profits of remanufactures are lower. In addition, when the AI-push for NP by the manufacturers is higher, the profits of all players on E-CLSCN are higher. When the AI-push for RP by remanufacturer is higher, the profits of the remanufacturers are higher, but the profits of the manufacturers and the whole E-CLSCN are lower. (3) The condition of the consumers' preference for products and the AI-push are dynamic, which is similar to those in the conditions of static. However, the impact of consumers' preference for NP (RP) and the AI-push on multi-period CLSCN becomes more obvious at the preliminary planning period. (4) Comparing dynamic and static conditions, when the AI-push is gradually increased during the planning period, although the profits of the manufacturers and remanufacturers increased, the increase is not obvious. The sensitivity of the demand markets to the investment of manufacturers' and remanufacturers' AI-push is gradually reducing. The marginal benefit of the investment of AI-push is gradually decreasing.

Enterprises management and environmentally sustainable development:

According to the sensitivity analysis of consumers' preference for products and AI-push on E-CLSCN equilibrium. In the sixth part of the research, the management inspiration is put forward from the government and enterprise: (1) Provide management advice for government's interventions and dynamic policies on E-CLSCN. (2) Propose enterprise management recommendations for consumers' dynamic preference levels, including the plans of AI-push and CSR.

Management implications:

(1) For supply chain management, this paper enriches the research scope of CLSCN and effectively promoted the level of closed-loop supply chain management.
(2) For policymakers (government), this paper gives the government a reference when developing dynamic intervention and subsidy mechanisms.
(3) For policy-implementers (enterprise), in the process of maximizing the economic interests of enterprises, how to balance environmental protection and government policies, this paper provides a reference for enterprises to develop dynamic strategic mechanisms from a new perspective.
(4) For sustainability, this paper helps manufacturers and remanufacturers improve their performance while providing advice to the government on optimizing the remanufacturing industry. Therefore, it is conducive to enhance the development of the remanufacturing industry in E-CLSCN. Ultimately achieving supply chain management sustainability, economic sustainability, and environmental sustainability.

The research in this paper is not only suitable for complex E-CLSCN with multiple manufacturers, multiple remanufacturers, and multiple demand markets. It is also suitable for a simply CLSC on e-channel. In addition, the research in this paper is not only suitable for E-CLSCN under collecting and remanufacturing by remanufacturers. It also suitable for remanufacturer and downstream retailers (recyclers) have full information, retailers participate in the sale and recycling of B2B, and the third-party recycler participates in the recycling on simple CLSN and complex CLSCN.

7.2. Limitations and Future Direction

Overall, this study addresses some novel issues. However, the authors acknowledge some limitations of this study, which can open new ways of investigation for future researchers. The content of this research can also be extensively expanded. Firstly, this paper considers E-CLSCN based on recycling and remanufacturing by remanufacturers, without considering the recycling behavior of other node companies. In the future, the issue of recycling competition among third-party recyclers and remanufacturers will be considered to extend the scope of this study. Secondly, this paper considers specific market demand and unconstrained funds among the participants in the supply chain of multi-node enterprises. Therefore, further in-depth, and longitudinal study is required to be established considering the uncertainty of market demand and financial constraints. Finally, this study only focusses on the profit maximizations, which neglect the consideration of cost reduction. Therefore, future researches are required to implement the same research model to measure the profit as well as cost reduction strategies to generalize the outcomes of the present study.

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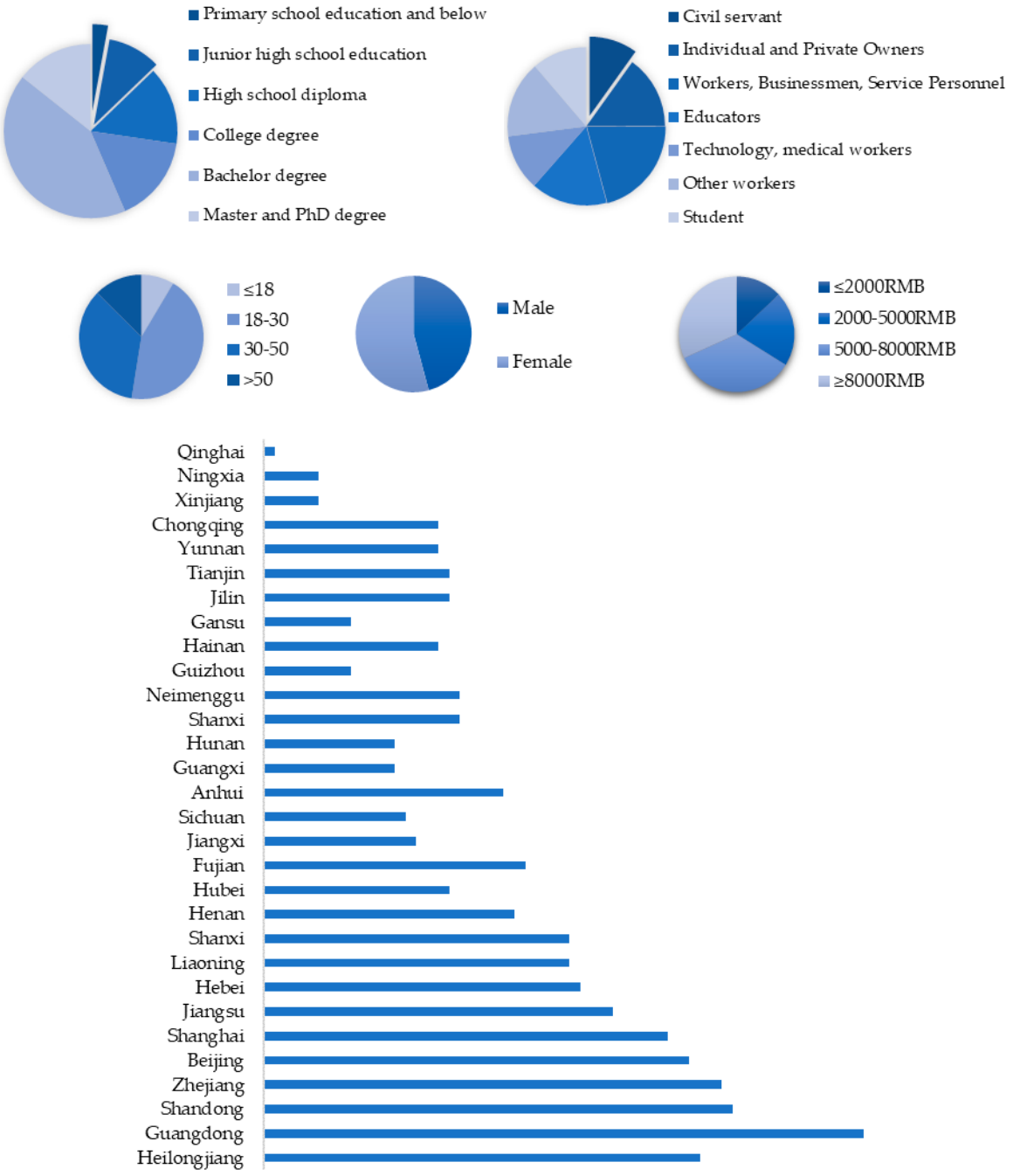
Appendix A

In order to better analyze consumers' preference for products and to ensure that this research direction is closer to the practical significance for E-CLSCN, the paper conducted a questionnaire survey through the Internet—The Questionnaire on Purchasing Preferences of RP and NP.

The content of the questionnaire mainly includes the following aspects:

(1) Information about respondents to the questionnaire.
(2) Preferences and actual purchase behavior for RP.
(3) Respondents believe or do not believe that remanufacturing products contribute to the sustainable development of resources.
(4) For the sustainable development of resources, respondents are willing to participate in recycling and remanufacturing operations in the future.

Through a web-based questionnaire (www.wjx.com), 800 questionnaires were distributed to 30 provinces and cities in China, and the effective questionnaire is 655. The specific investigator situation and questionnaire results are as follows:



Q1: Whether buying remanufactured products is conducive to the sustainable development of the environment

Option	Subtotal	Proportion
Yes	582	88.85%
No	73	11.15%
This question is valid for the number of times	655	

Q2: Have you ever purchased remanufactured products?

Option	Subtotal	Proportion
Yes	307	46.87%
I don't know if I bought a remanufactured product or not	154	23.51%
I'll consider buying in the future.	183	27.94%
I will not consider buying in the future	11	1.68%
This question is valid for the number of times	655	

Q3. If the quality and function of new products and remanufactured products are the same, would you buy new products or remanufactured products?

Option	Subtotal	Proportion
New product	349	53.28%
Remanufactured product	306	46.72%
This question is valid for the number of times	655	

Q4. Are you satisfied with the remanufactured products currently on the market? (including appearance, quality, etc.)?

Option	Subtotal	Proportion
Satisfied	354	54.05%
Dissatisfied	301	45.95%
This question is valid for the number of times	655	

Q5. New products and remanufactured products have the same functions, but the price of remanufactured products is lower. Would you buy remanufactured products?

Option	Subtotal	Proportion
Yes	551	84.12%
No	104	15.88%
This question is valid for the number of times	655	

Q6. New products and remanufactured products have the same functions, but remanufactured products are more expensive. Would you like to buy remanufactured products?

Option	Subtotal	Proportion
Yes	298	45.5%
No	357	54.5%
This question is valid for the number of times	655	

Q7. Do you think remanufactured products are an effective use of resources?

Option	Subtotal	Proportion
Yes	591	90.23%
No	64	9.77%
This question is valid for the number of times	655	

Q8. Have your family and friends ever bought remanufactured products?

Option	Subtotal	Proportion
Yes	278	42.44%
No	105	16.03%
I don't know	272	41.53%
This question is valid for the number of times	655	

Q9. Would you like to participate in the recycling of waste products, if the recycling of waste products gives you a certain fee?

Option	Subtotal	Proportion
Yes	558	85.19%
No	97	14.81%
This question is valid for the number of times	655	

Q10. In order to increase the sustainable development of resources, will you recommend that people around you buy remanufactured products?

Option	Subtotal	Proportion
Yes	571	87.18%
No	84	12.82%
This question is valid for the number of times	655	

Q11. If you were asked to add a small amount of money, would you participate in the exchange of old for new?

Option	Subtotal	Proportion
Yes	542	82.75%
No	113	17.25%
This question is valid for the number of times	655	

Survey results and findings:

1. Although 88% of respondents believe that the purchase of RP helps to improve the sustainable use of resources, only 46.87% of the respondents who purchased RP in actual. Following this, 23.51% of respondents are unclear whether the product they purchased is RP. Accordingly, 27.94% of the respondents have not purchased RP, but said they would consider purchasing in the future. It shows that consumers have a higher preference for RP, but their mobility is not strong. But future development is more optimistic.
2. Through surveys of satisfaction with RP, 54.05% of respondents expressed satisfaction with the quality and appearance of RP. Under the premise of no difference in quality between RP and NP, 53.28% of respondents prefer to purchase RP at the same price. However, 84.12% of respondents prefer to buy RP at a price lower than NP. Thus, 45.5% of respondents prefer to buy RP at a price higher than NP. Therefore, price and quality can effectively increase consumers' preference for RP.
3. It is optimistic that 90.23% of respondents believe that RP can increase the sustainable development of resources and are willing to recommend RP to friends and family. More than 80% of respondents are willing to participate in the recycling and remanufacturing industry to promote sustainable resource development

In summary, consumers have higher preferences for RP, but actual purchases need to be strengthened. It is optimistic that consumers believe that remanufactured products can effectively promote the sustainable development of resources and they are willing to invest in recycling operations in the future.

References

1. Govindan, K.; Soleimani, H.; Kannan, D. Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *Eur. J. Oper. Res.* **2015**, *240*, 603–626. [CrossRef]
2. Ferrer, G.; Swaminathan, J.M. Managing new and differentiated remanufactured products. *Eur. J. Oper. Res.* **2010**, *203*, 370–379. [CrossRef]
3. Abbey, J.D.; Blackburn, J.D.; Guide, V.D.R. Optimal pricing for new and remanufactured products. *J. Oper. Manag.* **2015**, *36*, 130–146. [CrossRef]
4. Zhang, C.T.; Ren, M.L. Closed-loop supply chain coordination strategy for the remanufacture of patented products under competitive demand. *Appl. Math. Model.* **2016**, *40*, 6243–6255. [CrossRef]
5. Savaskan, R.C.; Bhattacharya, S.; van Wassenhove, L.N. Closed-loop supply chain models with product remanufacturing. *Manag. Sci.* **2004**, *50*, 239–252. [CrossRef]
6. Long, X.; Shu, T.; Chen, S.; Wang, S.; Lai, K.K.; Yang, Y. Strategy analysis of recycling and remanufacturing by remanufacturers in closed-loop supply chain. *Sustainability* **2017**, *9*, 1818. [CrossRef]
7. He, P.; He, Y.; Xu, H. Channel structure and pricing in a dual-channel closed-loop supply chain with government subsidy. *Int. J. Prod. Econ.* **2019**, *213*, 108–123. [CrossRef]
8. Dong, J.; Zhang, D.; Nagurney, A. A supply chain network equilibrium model with random demands. *Eur. J. Oper. Res.* **2004**, *156*, 194–212. [CrossRef]

9. Haddadsisakht, A.; Ryan, S.M. Closed-loop supply chain network design with multiple transportation modes under stochastic demand and uncertain carbon tax. *Int. J. Prod. Econ.* **2018**, *195*, 118–131. [CrossRef]
10. Qiang, Q. The closed-loop supply chain network with competition and design for remanufactureability. *J. Clean. Prod.* **2015**, *105*, 348–356. [CrossRef]
11. Nie, J.; Zhong, L.; Yan, H.; Yang, W. Retailers' distribution channel strategies with cross-channel effect in a competitive market. *Int. J. Prod. Econ.* **2019**, *213*, 32–45. [CrossRef]
12. Hu, Q.; Xu, Q.; Xu, B. Introducing of online channel and management strategy for green agri-food supply chain based on pick-your-own operations. *Int. J. Environ. Res. Publ. Health* **2019**, *16*, 1990. [CrossRef]
13. Nagurney, A.; Cruz, J.; Dong, J.; Zhang, D. Supply chain networks, electronic commerce, and supply side and demand side risk. *Eur. J. Oper. Res.* **2005**, *164*, 120–142. [CrossRef]
14. Kong, L.; Liu, Z.; Pan, Y.; Xie, J.; Yang, G. Pricing and service decision of dual-channel operations in an O2O closed-loop supply chain. *Ind. Manag. Data Syst.* **2017**, *117*, 1567–1588. [CrossRef]
15. Debo, L.G.; Toktay, L.B.; van Wassenhove, L.N. Market segmentation and product technology selection for remanufacturable products. *Manag. Sci.* **2005**, *51*, 1193–1205. [CrossRef]
16. Matsumoto, M.; Chinen, K.; Endo, H. Paving the way for sustainable remanufacturing in Southeast Asia: An analysis of auto parts markets. *J. Clean. Prod.* **2018**, *205*, 1029–1041. [CrossRef]
17. Zhang, Y.; Wang, Y. Supply chain decisions considering heterogeneous consumer greenness preference and reservation utilities. *Int. J. Inf. Syst. Supply Chain Manag.* **2019**, *12*, 1–21. [CrossRef]
18. Abbey, J.D.; Meloy, M.G.; Guide, V.D.R.; Atalay, S. Remanufactured products in closed-loop supply chains for consumer goods. *Prod. Oper. Manag.* **2015**, *24*, 488–503. [CrossRef]
19. Sayedi, A.; Jerath, K.; Srinivasan, K. Competitive poaching in sponsored search advertising and its strategic impact on traditional advertising. *Mark. Sci.* **2014**, *33*, 586–608. [CrossRef]
20. Anand, K.S.; Aron, R. Group buying on the web: A comparison of price-discovery mechanisms. *Manag. Sci.* **2003**, *49*, 1546–1562. [CrossRef]
21. Savadkoohi, E.; Mousazadeh, M.; Torabi, S.A. A possibilistic location-inventory model for multi-period perishable pharmaceutical supply chain network design. *Chem. Eng. Res. Des.* **2018**, *138*, 490–505. [CrossRef]
22. Nagurney, A.; Dong, J.; Zhang, D. A supply chain network equilibrium model. *Transp. Res. Part E Logist. Transp. Rev.* **2002**, *38*, 281–303. [CrossRef]
23. Wang, W.; Zhang, P.; Ding, J.; Li, J.; Sun, H.; He, L. Closed-loop supply chain network equilibrium model with retailer-collection under legislation. *J. Ind. Manag. Optim.* **2019**, *15*, 199–219. [CrossRef]
24. Feng, L.; Govindan, K.; Li, C. Strategic planning: Design and coordination for dual-recycling channel reverse supply chain considering consumer behavior. *Eur. J. Oper. Res.* **2017**, *260*, 601–612. [CrossRef]
25. Du, S.; Zhu, J.; Jiao, H.; Ye, W. Game-theoretical analysis for supply chain with consumer preference to low carbon. *Int. J. Prod. Res.* **2015**, *53*, 3753–3768. [CrossRef]
26. Wang, Q.; Zhao, D.; He, L. Contracting emission reduction for supply chains considering market low-carbon preference. *J. Clean. Prod.* **2016**, *120*, 72–84. [CrossRef]
27. Ji, J.; Zhang, Z.; Yang, L. Carbon emission reduction decisions in the retail-/dual-channel supply chain with consumers' preference. *J. Clean. Prod.* **2017**, *141*, 852–867. [CrossRef]
28. Tong, W.; Mu, D.; Zhao, F.; Mendis, G.P.; Sutherland, J.W. The impact of cap-and-trade mechanism and consumers' environmental preferences on a retailer-led supply chain. *Resour. Conserv. Recycl.* **2019**, *142*, 88–100. [CrossRef]
29. Peng, H.; Pang, T.; Cong, J. Coordination contracts for a supply chain with yield uncertainty and low-carbon preference. *J. Clean. Prod.* **2018**, *205*, 291–302. [CrossRef]
30. Zhao, S.; Zhu, Q.; Cui, L. A decision-making model for remanufacturers: Considering both consumers' environmental preference and the government subsidy policy. *Resour. Conserv. Recycl.* **2018**, *128*, 176–186. [CrossRef]
31. Zhu, X.; Yu, L. The impact of warranty efficiency of remanufactured products on production decisions and green growth performance in closed-loop supply chain: Perspective of consumer behavior. *Sustainability* **2019**, *11*, 1420. [CrossRef]
32. Xu, L.; Wang, C. Sustainable manufacturing in a closed-loop supply chain considering emission reduction and remanufacturing. *Resour. Conserv. Recycl.* **2018**, *131*, 297–304. [CrossRef]
33. Ma, W.M.; Zhao, Z.; Ke, H. Dual-channel closed-loop supply chain with government consumption-subsidy. *Eur. J. Oper. Res.* **2013**, *226*, 221–227. [CrossRef]

34. Li, H.; Shen, Q.; Bart, Y. Local market characteristics and online-to-offline commerce: An empirical analysis of groupon. *Manag. Sci.* **2016**, *64*, 1860–1878. [CrossRef]
35. Li, H.; Kannan, P.K.; Viswanathan, S.; Pani, A. Attribution strategies and return on keyword investment in paid search advertising. *Mark. Sci.* **2016**, *35*, 831–848. [CrossRef]
36. Jin, Y.; Wang, S.; Hu, Q. Contract type and decision right of sales promotion in supply chain management with a capital constrained retailer. *Eur. J. Oper. Res.* **2015**, *240*, 415–424. [CrossRef]
37. Zhou, Y.W.; Cao, B.; Tang, Q.; Zhou, W. Pricing and rebate strategies for an e-shop with a cashback website. *Eur. J. Oper. Res.* **2017**, *262*, 108–122. [CrossRef]
38. Nagurney, A.; Dutta, P. Supply chain network competition among blood service organizations: A generalized nash equilibrium framework. *Ann. Oper. Res.* **2019**, *275*, 551–586. [CrossRef]
39. Wu, X.; Nie, L.; Xu, M.; Yan, F. A perishable food supply chain problem considering demand uncertainty and time deadline constraints: Modeling and application to a high-speed railway catering service. *Transp. Res. Part E Logist. Transp. Rev.* **2018**, *111*, 186–209. [CrossRef]
40. Seuring, S.; Müller, M. From a literature review to a conceptual framework for sustainable supply chain management. *J. Clean. Prod.* **2008**, *16*, 1699–1710. [CrossRef]
41. Shashi; Singh, R.; Centobelli, P.; Cerchione, R. Evaluating partnerships in sustainability-oriented food supply chain: A five-stage performance measurement model. *Energies* **2018**, *11*, 3473. [CrossRef]
42. Shashi, S.; Cerchione, R.; Centobelli, P.; Shabani, A. Sustainability orientation, supply chain integration, and SMEs performance: A causal analysis. *Benchmark. Int. J.* **2018**, *25*, 3679–3701.
43. Giri, B.C.; Mondal, C.; Maiti, T. Analysing a closed-loop supply chain with selling price, warranty period and green sensitive consumer demand under revenue sharing contract. *J. Clean. Prod.* **2018**, *190*, 822–837. [CrossRef]
44. Hammond, D.; Beullens, P. Closed-loop supply chain network equilibrium under legislation. *Eur. J. Oper. Res.* **2007**, *183*, 895–908. [CrossRef]
45. Pedram, A.; Pedram, P.; Yusoff, N.B.; Sorooshian, S. Development of closed-loop supply chain network in terms of corporate social responsibility. *PLoS ONE* **2017**, *12*, e0174951. [CrossRef]
46. Allevi, E.; Gnudi, A.; Konnov, I.V.; Oggioni, G. Evaluating the effects of environmental regulations on a closed-loop supply chain network: A variational inequality approach. *Ann. Oper. Res.* **2018**, *261*, 1–43. [CrossRef]
47. Zhalechian, M.; Tavakkoli-Moghaddam, R.; Zahiri, B.; Mohammadi, M. Sustainable design of a closed-loop location-routing-inventory supply chain network under mixed uncertainty. *Transp. Res. Part E Logist. Transp. Rev.* **2016**, *89*, 182–214. [CrossRef]
48. Tao, Z.G.; Guang, Z.Y.; Hao, S.; Song, H.J.; Xin, D.G. Multi-period closed-loop supply chain network equilibrium with carbon emission constraints. *Resour. Conserv. Recycl.* **2015**, *104*, 354–365. [CrossRef]
49. Jiang, C.; Zhang, Y.; Bu, M.; Liu, W. The effectiveness of government subsidies on manufacturing innovation: Evidence from the new energy vehicle industry in China. *Sustainability* **2018**, *10*, 1692. [CrossRef]
50. Chemama, J.; Cohen, M.; Lobel, R.; Perakis, G. Consumer subsidies with a strategic supplier: Commitment vs. flexibility. *Manag. Sci.* **2019**, *65*, 681–713. [CrossRef]
51. Panda, S.; Modak, N.M.; Cárdenas-Barrón, L.E. Coordinating a socially responsible closed-loop supply chain with product recycling. *Int. J. Prod. Econ.* **2017**, *188*, 11–21. [CrossRef]