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Research on Green Closed-Loop Supply Chain Considering Manufacturer's Fairness Concerns and Sales Effort

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Abstract: To reduce resource loss and environmental pollution, green CLSC has become a hot issue that manufacturing enterprises pay attention to. In green CLSC, manufacturers would pay attention to the fairness of profit distribution when making sales efforts. Therefore, this paper studies a green closed-loop supply chain (CLSC) considering manufacturer sales efforts and fairness concerns. Then, the centralized model and decentralized model are built and analyzed. Afterward, a profit-sharing contract between members is designed to coordinate the supply chain. We made the following observations: (1) The manufacturers' fairness concerns would reduce product green degree, sales effort and recycling rate of used products, which is not conducive to the sustainable development of the green closed-loop supply chain. (2) When the manufacturers' fairness concerns are gradually strengthened, the optimal decisions would deviate even more from the optimal equilibrium results. (3) When the coefficient of fairness concerns and the ratio of profit-sharing satisfy a certain range, Pareto improvement can be effectively realized.

Keywords: green closed-loop supply chain; fairness concerns; sales effort; profit-sharing contract

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1. Introduction

Today, the world has entered the mobile era. According to the CNNIC report, the number of Internet users in China is 1.032 billion as of December 2022 [1]. Smartphones are the most commonly used tool for surfing the Internet. Smartphones are updated at a fast pace. Apple launches a new product every year, and Huawei updates several series of smartphones every year. Most of the used phones are in an idle state or discarded, resulting in a waste of resources. For example, nearly 80% of used smartphones in China are unused or discarded [2]. In addition, the batteries and electronic components in smartphones can seriously pollute the environment [3]. Therefore, device manufacturers have implemented green CLSC. For example, Huawei has developed green smartphones and recycled used products globally. Apple has also been upholding green principles in the development and production of Apple products. In the 2030 Agenda for Sustainable Development, the agenda calls on countries around the world to take action to achieve the green development and adopt sustainable consumption. Based on this background, strengthening the development and management of green CLSC has become the key to economic development and environmental protection.

In reality, manufacturers would invest money in advertising and make efforts to increase the sales of products [4]. Manufacturers invest huge costs in sales efforts with the aim of increasing the market share and reaping profit returns. However, most of the profits are divided up by retailers in the process of selling. For example, Huawei invests a large amount of R&D and sales effort cost, with a profit margin of only 8%, yet retailers have profit margins of 10%–15% or even up to 20% [5]. Fairness in the distribution of profits among supply chain members is the key to the formation of cooperative relationships, operational efficiency and long-term stability of the supply chain [6]. Currently, manufacturers are investing more funds for the development of green CLSC. They would pay more attention to the fairness of profit distribution, which is the behavior called fairness concerns [7]. Fairness concerns have been previously confirmed by many studies. Therefore, when manufacturers are required to make sales efforts, how do manufacturers' fairness concerns affect the green CLSC? This has become a pressing issue in green CLSC. At present, most researchers study green CLSC from green supply chains and closed-loop supply chains. To study the green supply chain, product greenness is introduced as a typical variable [8,9]. In the study of CLSC, the recycling rate is discussed [10,11]. In traditional supply chain research, scholars have assumed that supply chain members have fairness concerns. To research practical irrational behavior, scholars have gradually combined fairness concerns and green supply chain or CLSC, respectively. However, this paper incorporates manufacturers' fairness concerns into green CLSC. In actual life, manufacturers are more influential in promoting products through sales efforts, such as advertising and promotion, and retailers provide related services in the sales process. Based on the above background, this paper focuses on how the manufacturers' fairness concerns affect the pricing of green CLSC and how to optimize the members' decision-making and design a coordinated contract in green CLSC.

This paper studies green CLSC in which manufacturers make sales effort. Manufacturers have fairness concerns. Based on the Stackelberg game theory, the centralized decision model and decentralized decision model with manufacturers' fairness neutrality and fairness concerns are constructed. Through theoretical comparison and numerical simulation, how fairness concerns affect green CLSC is explored. Finally, a contract is designed to coordinate green CLSC with fairness concerns. This paper aims to address the following three questions:

(1) How do manufacturers' fairness concerns affect the decisions of the members of green CLSC?
(2) What are the impacts of manufacturers' fairness concerns on the product green degree and manufacturers' sales effort?
(3) What coordination mechanism should be adopted to optimize green CLSC with manufacturers' fairness concerns?

The specific contributions of this paper are as follows: (1) The green CLSC pricing decision where the manufacturer makes the sales effort is studied. In related studies, it is assumed that the retailer makes the sales effort, and the manufacturers' sales effort has not been considered in studies of green CLSC. Therefore, this paper will contribute to green CLSC decisions. (2) The impact of manufacturers' fairness concerns on green CLSC is investigated. Instead of assuming that decision-makers are perfectly rational, this paper will be helpful to study fairness concerns in green CLSC. (3) A profit-sharing contract is designed to address the impact of manufacturers' fairness concerns on green CLSC. This paper provides ideas for designing contracts for enterprises in green CLSC.

The content of this article is arranged as follows: In Section 2, the relevant literature is summarized. Section 3 describes the problem of green CLSC and defines parameter symbols and assumptions. Section 4 analyzes the different models when manufacturers consider fairness concerns. Section 5 designs a profit-sharing contract to coordinate the green CLSC. Section 6 presents a numerical simulation. Section 7 summarizes the conclusion.

2. Literature Review

In green CLSC, scholars have carried out research from government subsidies [12], uncertainty demand [13], cost differences [14] and channel selection [15]. Three aspects of the literature are related to our research, namely, decision-making and coordination of green CLSC, supply chain considering sales efforts and supply chain considering fairness concerns.

2.1. Green Closed-Loop Supply Chain

The green CLSC solves the contradiction between economy and environment and achieves green development. At present, there is no authoritative specific definition of green CLSC. Some scholars regard green CLSC as ecological closed-loop supply chain [16]. Atasu argued that green CLSC should leverage investments in the recycling of used products to achieve maximum environmental improvement [17]. Neto et al. identified the closed-loop supply chain with the best economic and environmental benefits as green CLSC [18]. Most scholars regard green CLSC as the integration of green supply chain and closed-loop supply chains. The green CLSC not only meets the economic objectives of closed-loop supply chains but also meets the environmental objectives of green supply chains. Few studies are directly about green CLSC, most of which interpret green CLSC from the perspective of green supply chain and closed-loop supply chain. Ghosh and Shah discussed how the channel structure influenced the product green degree, price and profit in the second-echelon green supply chain composed of a retailer and a manufacturer [19]. Ghosh and Shah discussed the coordination of cost-sharing contracts for the green supply chain [20]. Li et al. concluded that centralized decision-making would increase retail prices in a dual-channel green supply chain [21]. Bai and Tang considered their environmental input and discussed the cooperation between manufacture and retailer [8]. Jiang and Li designed the effective revenue-sharing contract for a second-echelon green supply chain [9]. Ma et al. discussed the pricing strategy of a second-echelon green supply chain composed of a retailer and two complementary manufacturers [22]. Cao et al. discussed the influence of government subsidies on pricing and green efforts [23]. Savaskan et al. discussed the efficiency of different channels on closed-loop supply chain in three different recycling modes by assuming that all parties were completely rational [10]. Choi studied the pricing under different recycling modes [11]. Ferrer et al. discussed the various pricing strategy of new products and remanufacturing products in the CLSC [24]. Zheng et al. investigated a CLSC with a third-party recycling remanufacturer and established a pricing and coordination model under patent protection [25]. Xie et al. studied a dual-channel CLSC model of online and offline sales-services under a revenue-sharing contract [26]. Since then, Xie coordinated the CLSC led by battery manufacturers through contracts under different recycling modes and optimized the problem of an imperfect power battery recycling system [27]. Giri and Mondal et al. compared how the green degree, price and product life span influenced the product demand in the CLSC [28]. Yao et al. introduced the corporate social responsibility of manufacturer and retailer into the CLSC involving third-party recycling and designed contracts to coordinate the CLSC [29].

2.2. Supply Chain Considering Sales Effort

To sell the green products to the market, it is necessary to pay the cost to publicize green products and conduct green consumption. At present, many scholars have investigated the sales effort in the supply chain. Ma et al. studied the interaction between product quality and sales effort in different power-dominated supply chains [30] and then designed a two-part tariff and cost-sharing contract to coordinate the supply chain [31]. Dai et al. studied the coordination of buyback contracts under the promotion efforts of risk-averse sellers by using the CVaR method [32]. Gao et al. found that a low-price promotion strategy was better than the green marketing strategy [33]. Zerang et al. discussed the influence of sales effort and recycling number on decision variables in the manufacturer-led CLSC [34]. Li et al. considered the retailers' sales effort and the government's subsidies in the remanufactured product supply chain [35]. Wang et al. discussed pricing strategy considering sales effort and demand uncertainty in the dual-channel supply chain [36]. Shang et al. discussed the product greenness and sales efforts influenced by the government subsidies in the green CLSC [37]. Yao et al. discussed the impact of corporate social responsibility on closed-loop supply chain when manufacturers and retailers are respectively responsible for sales effort [38]. Most research scholars pay attention to retailers' sales effort, while there is less research on the manufacturers' sales efforts for market promotion.

2.3. Supply Chain with Fairness Concerns

At present, scholars have considered fairness concerns in the decision-making and coordination research of the supply chain. Fehr et al. found that people were extremely concerned about whether the distribution of profits was fair, which is called fairness concerns behavior [39]. Ho et al. used the utility function to describe the fairness concerns of supply chain members [40]. Katok and Pavlov pointed out that the fairness concerns, bounded rationality and incomplete information would lead to channel inefficiencies in the supply chain [41]. Yao and Teng explored how the manufacturers' fairness concerns influence the CLSC and discussed an overall optimal decision-making process with the participation of third-party recyclers [42]. Shi et al. introduced fairness concerns and product greening efficiency into the green design research in the supply chain [43]. Wang et al. studied the impact of the network platforms' fairness concerns on the sales and recycling decisions of E-CLSC based on different power structures [44]. Gong et al. analyzed the impact of the manufacturers' corporate social responsibility and fairness preferences on pricing decisions and corporate earning [45]. Yan et al. discussed the impact of manufacturers' fairness concerns and retailers' fairness concerns on the fresh produce supply chain in a Nash framework [46]. Hu et al. studied the impact of retailers' fairness concerns on green supply chain decisions, with retailers making green marketing effort input [47]. Some scholars have designed contracts to optimize supply chains considering the behavior of fairness concerns. Cui et al. coordinated the two-echelon supply chain with fairness concerns by determining a reasonable wholesale price [48]. Du et al. studied a supply chain contract considering the impact of fairness concerns [49]. Pu et al. considered the retailer's fairness concerns to explore the promotion efforts and operation efficiency and designed a revenue-sharing contract [50]. Nie and Du coordinated the two-way fairness concerns of the distributor by a combination of a quantity discount contract and fixed fee payments [51]. Han et al. found that the manufacturers' fairness concerns were unfavorable to all members [52]. Wang et al. constructed a revenue-sharing contract coordination model that considered the risk aversion and fairness preferences [53]. Yoshihara and Matsubayashi provided a game-theoretic analysis for channel coordination in a two-level supply chain by determining the ideal distribution ratio coefficient [54]. The above-mentioned literatures confirm that the fairness concerns of enterprises' behavior play a crucial role in the cooperation and development of the supply chain. Therefore, it would be more practical to incorporate fairness concerns into the green CLSC.

3. Description and Assumptions

A green CLSC composed of a manufacturer (M) and a retailer (R) is considered in this paper. In the forward supply chain, M uses raw materials to produce new green products and available materials to produce remanufactured products. The products are wholesaled to R. Meanwhile, M invests in advertising to promote green products, and then R sells green products and provides corresponding services in the sales process, such as customer service, warehousing, logistics and after-sales service [44]. In the reverse supply chain, M recycles used products from consumers. To study the green closed-loop supply chain, the product greenness variable and the recycling rate are introduced [8–11]. The parameter symbols of definition and assumptions are shown in Table 1.

Table 1. Parameter symbol definitions and assumptions.

Symbol	Definitions and Assumptions
M	The manufacturer is abbreviated to M.
R	The retailer is abbreviated to R.
a_0	The basic demand scale of market, $a_0 > 0$.
c_m	Unit manufacturing cost of new product using raw materials, $c_m > 0$.
c_r	Unit manufacturing cost of new product using available materials, $c_m > c_r > 0$.
m	Unit recycling price of used product, $0 < m \leq c_m - c_r$.
w	Unit wholesale price of product, $w > c_m$.
p	Unit retail price of product, $p > w$.
g	Product green degree, $g \geq 0$. The green R&D cost paid by M is $\frac{c_1 g^2}{2}$, where c_1 is the green R&D cost coefficient, $c_1 > 0$ [55].
y	Sales effort degree, $y \geq 0$. The cost of sales effort paid by M is $\frac{c_2 y^2}{2}$, where c_2 is the cost coefficient of sales effort, $c_2 > 0$ [56].
β	Recycling rate of used product, $0 < \beta < 1$. The recycling rate of used product is affected by the product green degree. Set $\beta = \theta g$, where θ is the recycling coefficient, $\theta > 0$ [41].
s	R's service level, $s > 0$. The service cost paid by R is $\frac{c_3 s^2}{2}$, where c_3 is the service level cost coefficient, $c_3 > 0$ [44].
D	Market demand, which is affected by the retail price, product green degree, sales effort degree and service level. The market demand function is $D = a_0 - bp + kg + ly + \mu s$; b is the consumers' sensitivity coefficient to retail price, k is the product green effect coefficient, l is the sales effort effect coefficient, and μ is the service level effect coefficient; $b, k, l, \mu > 0, a_0 > bp$.

4. Analysis of Model

In this paper, the centralized and decentralized model are considered and discussed. Models are constructed based on Stackelberg's game theory. The Stackelberg game has been widely used in various studies of supply chain management. In the Stackelberg game, game leaders develop a strategy in advance based on available information. Followers respond by developing coping strategies based on their own situations and their observations. The equilibrium result in the centralized model is represented by the superscript "c*". The equilibrium result in the decentralized model with fairness neutrality is represented by the superscript "d*". The equilibrium result in the decentralized model with fairness concerns is represented by the superscript "d*" and the subscript "λ".

4.1. Centralized Model

In the centralized model, M and R are considered as a whole, and their goal is to maximize the profit of the green CLSC. Thus, overall profit of the green CLSC is the sum of manufacturers' profit and the retailers' profit, which can be expressed as

$$\begin{aligned} \underset{p,g,y,s}{Max}\,\pi^c &= D(p - c_m) + D\beta(c_m - c_r - m) - \frac{c_1 g^2}{2} - \frac{c_2 y^2}{2} - \frac{c_3 s^2}{2} \\ &= (a_0 - bp + kg + ly + \mu s)(p - c_m + \theta g(c_m - c_r - m)) - \frac{c_1 g^2}{2} - \frac{c_2 y^2}{2} - \frac{c_3 s^2}{2} \end{aligned} \quad (1)$$

According to the concavity of profit function, the following propositions are obtained.

Proposition 1. In the centralized model, in order to maximize collective profits, the decisions made by M and R are as follows:

The optimal product green degree is $g^{c*} = \frac{c_2 c_3 (a_0 - bc_m)(k + b\theta(c_m - c_r - m))}{A}$. The optimal sales effort degree is $y^{c*} = \frac{c_1 c_3 l (a_0 - bc_m)}{A}$. The optimal retail price is $p^{c*} = \frac{c_2 c_3 (a_0 - bc_m)\left(c_1 - \theta\left(\begin{array}{c} c_m - \\ c_r - m \end{array}\right)\left(\begin{array}{c} k + \\ b\theta(c_m - c_r - m) \end{array}\right)\right)}{A} + c_m$. The optimal service level is

$s^{c*} = \frac{\mu c_1 c_2 (a_0 - bc_m)}{A}$. The optimal recycling rate is $\beta^{c*} = \frac{c_2 c_3 \theta (a_0 - bc_m)(k + b\theta(c_m - c_r - m))}{A}$. The optimal market demand is $D^{c*} = \frac{bc_1 c_2 c_3 (a_0 - bc_m)}{A}$. The optimal system profit is $\pi^{c*} = \frac{c_1 c_2 c_3 (a_0 - bc_m)^2}{2A}$. To obtain the above balanced results, three conditions need to be met: $0 < \beta^{c*} < 1$, $a_0 > bp^c$ and $0 < \theta < \frac{B - c_2 c_3 k (a_0 + b(c_m - 2(c_r + m)))}{2bc_2 c_3 (c_m - c_r - m)(a_0 - b(c_r + m))}$, where

$$A = c_3\left(bc_2\left(2c_1 - \theta\left(c_m - c_r - m\right)\left(k + b\theta\left(c_m - c_r - m\right)\right)\right) - c_1 l^2 - c_2 k^2\right) - c_1 c_2 \mu^2 > 0,$$

$$B = \sqrt{c_2 c_3\left(c_2 c_3 k^2 (a_0 + b(c_m - 2(c_r + m)))^2 + 4b\left(c_m - c_r - m\right)\left(a_0 - b\left(c_r + m\right)\right)\left(c_3\left(2bc_1 c_2 - c_1 l^2 - c_2 k^2\right) - c_1 c_2 \mu^2\right)\right)}.$$

The proof of Proposition 1 is provided in Appendix A.

4.2. Decentralized Model with Fairness Neutrality

In the decentralized model, the supply chain decision sequence is as follows: Firstly, M, as the leader, sets the optimal wholesale price, optimal product green degree and optimal sales effort degree to maximize own profit. Then R, as the follower, determines the optimal retail price and service level according to M's decision information. The equilibrium solution is solved by backward induction. First, the decision of R is solved, and then the equilibrium solution of M is solved. In the decentralized model, both M and R prioritize their own profits. The profit functions are as follows:

$$\underset{w,g,y}{Max}\,\pi_m^d = (a_0 - bp + kg + ly + \mu s)(w - c_m + \theta g(c_m - c_r - m)) - \frac{c_1 g^2}{2} - \frac{c_2 y^2}{2} \quad (2)$$

$$\underset{p,s}{Max}\,\pi_r^d = (a_0 - bp + kg + ly - \mu s)(p - w) - \frac{c_3 s^2}{2} \quad (3)$$

Proposition 2. In the decentralized model, in order to maximize their own profits, the decisions made by M and R are as follows:

The optimal unit wholesale price is $w^{d*} = \frac{(a_0 - bc_m)\left(A + c_3\left(c_1 l^2 + c_2 k^2\right)\right)}{bC} + c_m$. The optimal product green degree is $g^{d*} = \frac{c_2 c_3 (a_0 - bc_m)(k + b\theta(c_m - c_r - m))}{C}$. The optimal sales effort degree is $y^{d*} = \frac{c_1 c_3 l (a_0 - bc_m)}{C}$. The optimal unit retail price is $p^{d*} = \frac{(a_0 - c_m)\left(A + c_3\left(bc_1 c_2 + c_1 l^2 + c_2 k^2\right)\right)}{bC} + c_m$. The optimal service level is $s^{d*} = \frac{c_1 c_2 \mu (a_0 - bc_m)}{C}$. The optimal recycling rate is $\beta^{d*} = \frac{c_2 c_3 \theta (a_0 - bc_m)(k + b\theta(c_m - c_r - m))}{C}$. The optimal market demand is $D^{d*} = \frac{bc_1 c_2 c_3 (a_0 - bc_m)}{C}$. The optimal profits are $\pi_m^{d*} = \frac{c_1 c_2 c_3 (a_0 - bc_m)^2}{2C}$ and $\pi_r^{d*} = \frac{c_1^2 c_2^2 c_3 (a_0 - bc_m)^2 \left(2bc_3 - \mu^2\right)}{2C^2}$. The optimal system profit is $\pi^{d*} = \frac{c_1 c_2 c_3 (a_0 - bc_m)^2 \left(C + c_1 c_2 \left(2bc_3 - \mu^2\right)\right)}{2C^2}$. Among them, $C = c_3\left(bc_2(4c_1 - \theta(c_m - c_r - m)(2k + b\theta(c_m - c_r - m))) - c_1 l^2 - c_2 k^2\right) - 2c_1 c_2 \mu^2$. The proof is provided in Appendix B. By comparing the supply chain profits of two different models, $\pi^{c*} = \left(1 + \frac{\left(c_2\left(bc_3(2c_1 - k\theta(c_m - c_r - m)) - c_1\mu^2\right)\right)^2 - Abc_2 c_3 k\theta(c_m - c_r - m)}{A\left(C + c_1 c_2\left(2bc_3 - \mu^2\right)\right)}\right)\pi^{d*} > \pi^{d*}$, it is clear that the supply chain profit is higher in centralized model.

The proof of Proposition 2 is provided in Appendix B.

4.3. Decentralized Model with Fairness Concerns

Manufacturers invest in the green R&D and sales effort. To maximize its own utility, M would be more concerned about the distribution of profits [49]. Assume that λ_0 means the fairness concerns coefficient, and $\lambda_0 > 0$. The M's utility function is set as follows:

$$u_m^d = \pi_m^d - \lambda_0\left(\pi_r^d - \pi_m^d\right) = (1+\lambda_0)\pi_m^d - \lambda_0\pi_r^d \tag{4}$$

Set $U_m^d \equiv \frac{u_m^d}{1+\lambda_0} = \pi_m^d - \frac{\lambda_0}{1+\lambda_0}\pi_r^d$, $\lambda = \frac{\lambda_0}{1+\lambda_0}$. The fairness concerns coefficient is expressed by λ, $\lambda \in [0,1)$. When $\lambda_0 = 0$, $\lambda = 0$, M does not care the fairness. When $\lambda_0 \to \infty$, $\lambda \to 1$, M is extremely concerned about fairness concerns. Therefore, the function (4) can be updated and expressed as

$$\begin{aligned} U_m^d &= \pi_m^d - \lambda\pi_r^d \\ &= (a_0 - bp + kg + ly + \mu s)(w(1+\lambda) - \lambda p - c_m + \theta g(c_m - c_r - m)) - \frac{c_1 g^2}{2} - \frac{c_2 y^2}{2} + \lambda\frac{c_3 s^2}{2} \end{aligned} \tag{5}$$

Using the backward induction method, the reaction decision functions of R obtained from $\frac{\partial \pi_r^d}{\partial p} = 0$ and $\frac{\partial \pi_r^d}{\partial s} = 0$ are still $p^d = \frac{c_3(a_0+gk+bw+ly)-w\mu^2}{2bc_3-\mu^2}$ and $s^d = \frac{(a_0+gk-bw+ly)\mu}{2bc_3-\mu^2}$. Then, to solve $\frac{\partial U_m^d}{\partial w} = 0$, $\frac{\partial U_m^d}{\partial g} = 0$ and $\frac{\partial U_m^d}{\partial y} = 0$, the optimal functions in the M's utility function are obtained as follows: $g_\lambda^{d*} = \frac{c_2c_3(a_0-bc_m)(k+b\theta(c_m-c_r-m))}{C+\lambda c_1c_2(2bc_3-\mu^2)}$, $y_\lambda^{d*} = \frac{c_1c_3 l(a_0-bc_m)}{C+\lambda c_1c_2(2bc_3-\mu^2)}$ and $w_\lambda^{d*} = \frac{(a_0-bc_m)\left(A+\lambda c_1c_2\left(2bc_3-\mu^2\right)+c_3\left(c_1l^2+c_2k^2\right)\right)}{b(C+\lambda c_1c_2(2bc_3-\mu^2))} + c_m$.

Thus, the optimal functions in the R's profit function are obtained as follows: $p_\lambda^{d*} = \frac{c_2(a_0-bc_m)\left(A+c_1c_2\left((1+2\lambda)bc_3-\mu^2\right)+c_3\left(c_1l^2+c_2k^2\right)\right)}{b(C+\lambda c_1c_2(2bc_3-\mu^2))} + c_m$, $s_\lambda^{d*} = \frac{c_1c_2\mu(a_0-bc_m)}{C+\lambda c_1c_2(2bc_3-\mu^2)}$.

Therefore, the optimal recycling rate is $\beta_\lambda^{d*} = \frac{c_2c_3\theta(a_0-bc_m)(k+b\theta(c_m-c_r-m))}{C+\lambda c_1c_2(2bc_3-\mu^2)}$. The optimal market demand is $D_\lambda^{d*} = \frac{bc_1c_2c_3(a_0-bc_m)}{C+\lambda c_1c_2(2bc_3-\mu^2)}$. The optimal profit is $\pi_{r\lambda}^{d*} = \frac{c_1^2c_2^2c_3(a_0-bc_m)^2\left(2bc_3-\mu^2\right)}{2(C+\lambda c_1c_2(2bc_3-\mu^2))^2}$, $\pi_{m\lambda}^{d*} = \frac{c_1c_2c_3(a_0-bc_m)^2\left(C+2\lambda c_1c_2\left(2bc_3-\mu^2\right)\right)}{2(C+\lambda c_1c_2(2bc_3-\mu^2))^2}$ and $\pi_\lambda^{d*} = \frac{c_1c_2c_3(a_0-bc_m)^2\left(C+c_1c_2(1+2\lambda)\left(2bc_3-\mu^2\right)\right)}{2(C+\lambda c_1c_2(2bc_3-\mu^2))^2}$. The M's maximum utility can be obtained as $U_m^{d*} = \frac{c_1c_2c_3(a_0-bc_m)^2}{2(C+\lambda c_1c_2(2bc_3-\mu^2))}$. When $\lambda = 0$, the equilibrium results are not be affected by the fairness concerns.

Proposition 3. When $\lambda > 0$, the equilibrium results satisfy: $\frac{\partial w_\lambda^{d*}}{\partial \lambda} > 0$, $\frac{\partial g_\lambda^{d*}}{\partial \lambda} < 0$, $\frac{\partial y_\lambda^{d*}}{\partial \lambda} < 0$, $\frac{\partial p_\lambda^{d*}}{\partial \lambda} > 0$, $\frac{\partial s_\lambda^{d*}}{\partial \lambda} < 0$, $\frac{\partial \beta_\lambda^{d*}}{\partial \lambda} < 0$, $\frac{\partial D_\lambda^{d*}}{\partial \lambda} < 0$.

The proof of Proposition 3 is provided in Appendix C.

Proposition 3 shows that the unit wholesale price and unit retail price are positively correlated with fairness concerns coefficient. The service level, green degree, sales effort, recycling rate and market demand are negatively correlated with fairness concerns coefficient. In other words, if the M cares about the profit distribution, it would choose to increase the unit wholesale price to increase the marginal income and reduce the cost by reducing the product green degree and putting in less sales effort. In the same way, R would also increase the unit retail price to protect its own interest and reduce the input cost of the service level. Because of the "selfish" behaviors of M and R, the quality of green products would decline, and the promotion of green products and service level would tend to be conservative, which directly reduce the willingness of consumers to purchase green products and gives common products a greater chance to compete. For the sustainable development of the environment, the higher M's fairness concerns are, the lower the product green degree is, which may cause more serious environmental pollution of used products and would be more unfavorable to recycle used products and reduce the market demand. It is not conducive to recycling used products, the cultivation of green consumption and environmental protection. In a word, the goal of manufacturers' fairness concerns behavior is to ensure the fair distribution of profits in the green CLSC.

Corollary 1. Considering M's fairness concerns behavior, the relationship among M's profit, R's profit and system profit would be obtained: $\frac{\partial \pi_{m\lambda}^{d*}}{\partial \lambda} < 0$, $\frac{\partial \pi_{r\lambda}^{d*}}{\partial \lambda} < 0$, $\frac{\partial \pi_{\lambda}^{d*}}{\partial \lambda} < 0$.

The proof of Corollary 1 is provided in Appendix D.

Corollary 1 shows that the partial derivative of profit function of M, R and overall supply chain with respect to fairness concerns coefficient are always less than 0. Obviously, the profits of M, R and overall supply chain always decrease with increasing of M's fairness concerns. In other words, M believes the distribution of channel profits is unfair, whose decision-making behavior not only damages the profits of the supply chain but also reduces the efficiency, which is not conducive to cooperation between both parties and the sustainable development of green CLSC.

Corollary 2. When M has fairness concerns, the relationship of M's profit and R's profit is $\pi_{m\lambda}^{d*} > \pi_{r\lambda}^{d*}$.

The proof of Corollary 2 is provided in Appendix E.

Corollary 2 shows that M would obtain more profits in the supply chain if M cared more about the fairness concerns. The larger profit gap between the two parties becomes, the higher M's utility would be. That is to say, the more M cares about the fairness of channel profit distribution, the larger the proportion of profit earned by M in the system profit is. However, Corollary 2 indicates that profits of both parties have fallen with the increasing of M's fairness concerns.

Proposition 4. (1) $p_{\lambda}^{d*} > p^{d*} > p^{c*}$, $s_{\lambda}^{d*} < s^{d*} < s^{c*}$, $D_{\lambda}^{d*} < D^{d*} < D^{c*}$. (2) $w_{\lambda}^{d*} > w^{d*}$, $g_{\lambda}^{d*} < g^{d*} < g^{c*}$, $y_{\lambda}^{d*} < y^{d*} < y^{c*}$, $\beta_{\lambda}^{d*} < \beta^{d*} < \beta^{c*}$. (3) $\pi_{m\lambda}^{d*} < \pi_{m}^{d*}$, $\pi_{r\lambda}^{d*} < \pi_{r}^{d*}$, $\pi_{\lambda}^{d*} < \pi^{d*} < \pi^{c*}$.

The proof of Proposition 4 is provided in Appendix F.

According to Proposition 4, the equilibrium solutions of all variables are optimal under the centralized model. The system is more profitable under the centralized model regardless of whether M exhibits fair neutrality or fairness concerns. The joint decision of M and R can make all parties in the supply chain obtain more benefits and achieves Pareto optimality. Under the decentralized model, M's concerns about the fairness of profit distribution leads to double marginalization and reduces the efficiency of CLSC. M paying more attention to fair distribution would exacerbate the double marginalization and lead to a larger gap in the equilibrium results, which would damage M's profit. The system profit is higher under the centralized model, no matter whether M shows fairness neutrality or fairness concerns. To accurately predict and control M's fairness concerns, a certain coordination mechanism would be adopted to coordinate the situation.

5. Coordination Mechanism

To achieve coordination or Pareto improvement, a profit-sharing contract can be signed between supply chain members. M sets a lower wholesale price and R shares a portion of the profits from the sale of green products with the manufacturer. By signing the contract and adjusting the sharing proportion, supply chain members can maximize their own profit to adjust the channel profit distribution. In this paper, R and M are the provider and receiver of the profit-sharing contract, respectively. R shares part of the profits from selling green products to M as compensation. The sharing proportion coefficient is ϕ $(0 < \phi < 1)$, and R retains $1-\phi$ of sales profit. Under the coordination contract mechanism, the profit functions of both parties are, respectively,

$$\underset{w,g,y}{Max}\pi_{m\phi}^{d}=\begin{pmatrix} a_0-bp+ \\ kg+ly+\mu s \end{pmatrix}\begin{pmatrix} \phi(p-w)+w- \\ c_m+\theta g(c_m-c_r-m) \end{pmatrix}-\frac{c_1g^2}{2}-\frac{c_2y^2}{2}-\phi\frac{c_3s^2}{2} \quad (6)$$

$$\underset{p,s}{Max}\pi_{r\phi}^{d}=(1-\phi)\left((a_0-bp+kg+ly-\mu s)(p-w)-\frac{c_3s^2}{2}\right) \quad (7)$$

Thus, the utility function of M is

$$\underset{w,g,y}{Max}U_{m\phi}=\begin{pmatrix} a_0-bp+ \\ kg+ly+\mu s \end{pmatrix}\begin{pmatrix} w+(\phi-\lambda(1-\phi))(p-w)- \\ c_m+\theta g(c_m-c_r-m) \end{pmatrix}-\frac{c_1g^2}{2}-\frac{c_2y^2}{2}+(\lambda(1-\phi)-\phi)\frac{c_3s^2}{2} \quad (8)$$

Solving by reverse induction, the specific solution process is consistent with previous section. The optimal decisions under the maximization of M's utility are obtained as follows:

$w_{\phi}^{d*}=\frac{(a_0-bc_m)\begin{pmatrix} A+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2)+ \\ c_3(c_1l^2+c_2k^2) \end{pmatrix}}{b(C+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2))}+c_m$, $g_{\phi}^{d*}=\frac{c_2c_3(a_0-bc_m)(k+b\theta(c_m-c_r-m))}{C+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2)}$, $y_{\phi}^{d*}=\frac{c_1c_3l(a_0-bc_m)}{C+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2)}$.

The optimal decisions of R under maximum profit are as follows:

$p_{\phi}^{d*}=\frac{(a_0-bc_m)\begin{pmatrix} A+ \\ c_1c_2((\lambda(1-\phi)-\phi)(2bc_3-\mu^2)+bc_3)+ \\ c_3(c_1l^2+c_2k^2) \end{pmatrix}}{b(C+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2))}+c_m$, $s_{\phi}^{d*}=\frac{c_1c_2\mu(a_0-bc_m)}{C+(\lambda(1-\phi)-\phi)(2bc_3-\mu^2)}$, $\beta_{\phi}^{d*}=\frac{c_2c_3\theta(a_0-bc_m)(k+b\theta(c_m-c_r-m))}{C+(\lambda(1-\phi)-\phi)(2bc_3-\mu^2)}$, $D_{\phi}^{d*}=\frac{bc_1c_2c_3(a_0-bc_m)}{C+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2)}$.

The optimal profits of M, R and overall system can be calculated as follows:

$\pi_{m\phi}^{d*}=\frac{c_1c_2c_3(a_0-bc_m)^2\begin{pmatrix} C+ \\ c_1c_2(2\lambda(1-\phi)-\phi)(2bc_3-\mu^2) \end{pmatrix}}{2(C+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2))^2}$, $\pi_{r\phi}^{d*}=\frac{c_1^2c_2^2c_3(1-\phi)(a_0-bc_m)^2(2bc_3-\mu^2)}{2\begin{pmatrix} C+ \\ c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2) \end{pmatrix}^2}$.

$\pi_{\phi}^{d*}=\frac{c_1c_2c_3(a_0-bc_m)^2(C+c_1c_2(((1+2\lambda)(1-\phi)-\phi)(2bc_3-\mu^2)))}{2(C+c_1c_2(\lambda(1-\phi)-\phi)(2bc_3-\mu^2))^2}$.

The optimal utility of M is $U_{m\phi}^{*}=\frac{c_1c_2c_3(a_0-bc_m)^2}{2(C+c_1c_2(\lambda(1-\phi)(2bc_3-\mu^2)-2\phi bc_3))}$.

Proposition 5. When the profit-sharing proportion coefficient meets $0<\phi<\frac{(C+c_1c_2\lambda(2bc_3-\mu^2))(c_1c_2(2+\lambda)(2bc_3-\mu^2)-C)}{c_1^2c_2^2(1+\lambda)^2(2bc_3+\mu^2)^2}$, the profit-sharing contract can improve the green CLSC's efficiency. When $\phi^*=\frac{c_3(c_2((k+b\theta(c_m-c_r-m))^2+2bc_1\lambda)+c_1l^2)-c_1c_2\lambda\mu^2}{c_1c_2(1+\lambda)(2bc_3-\mu^2)}$, the green CLSC reaches the optimal state by the profit-sharing contract.

The proof of Proposition 5 is provided in Appendix G.

Proposition 5 shows that the coordination ratio of profit-sharing contract is closely related to λ. According to $0<\phi<\frac{(C+c_1c_2\lambda(2bc_3-\mu^2))(c_1c_2(2+\lambda)(2bc_3-\mu^2)-C)}{c_1^2c_2^2(1+\lambda)^2(2bc_3+\mu^2)^2}$, taking the partial derivative of its upper bound with respect to λ, there is $\frac{\partial\overline{\phi}}{\partial\lambda}=\frac{2(C+c_1c_2(2bc_3-\mu^2))^2}{c_1^2c_2^2(1+\lambda)^3(2bc_3-\mu^2)^2}>0$. It can be known that when λ increases gradually, the upper bound of the coordination parameter ϕ of profit-sharing contract also increases gradually, which means that the range of the profit-sharing proportion coefficient increases with the increase in the fairness concerns coefficient. The conclusion indicates that the more M cares about the fairness, the stronger its bargaining power is and the larger the profit-sharing ratio the manufacturer may obtain. However, R, as a party who shares the profits, should consider the most favorable sharing ratio of its own profit under the premise of compensating R's profits. Therefore, the optimal sharing proportion is the optimal value of the contract parameter that R is willing to choose. In this case, it can effectively reduce the damage of fairness concerns to green CLSC, maintain and promote the cooperation between M and R, facilitate the development of the green CLSC, promote the green consumption, reduce waste of resources, protect the environment and form a green economic model with a friendly and harmonious relationship between economy and environment.

6. Numerical Simulation

To verify the effectiveness and correctness of above conclusions, the effects of fairness concerns on green CLSC can be analyzed through numerical simulation. Setting $a_0 = 400$, $b = 4$, $c_1 = 400$, $c_2 = 200$, $c_3 = 30$, $c_m = 40$, $c_r = 20$, $m = 5$, $k = 20$, $l = 10$, $\mu = 5$ and $\theta = 0.2$, the profit-sharing ratio coefficient range is $0 < \phi < 0.917911$. Since this study is not specific to green products, the data used may be applied to a certain type of products, such as smartphones. The numerical simulation would compare the effects of the profit-sharing contract on the wholesale price, product green degree, M's sales effort degree, retail price, R's service level, market demand and recycling rate of used product. The red surface, blue surface, yellow surface and green surface in the following diagrams respectively represent the equilibrium results of the centralized model (c), decentralized model with fairness neutrality (dMfn), decentralized model with fairness concerns (dMfc) and profit-sharing contract coordination (pfcc).

In Figures 1–4, it is clear that the equilibrium results are in the centralized model, where M and R make decisions together. When M's fairness concerns increase, the product green degree, sales effort degree and recycling rate decrease, these equilibrium results are far lower than those in centralized model. In addition, the coordination effect of the profit-sharing contract can be verified by the figure. When the fairness concerns coefficient and profit-sharing proportion coefficient satisfy a certain condition, the benefits of green CLSC are optimized by profit sharing contract. Compared with the situation where M does not care about fairness, the equilibrium solutions of product greenness, sales effort and recovery rate are close to those in the centralized model.

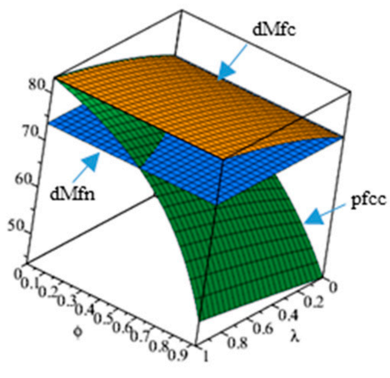

Figure 1. Effects of fairness concerns and profit-sharing on wholesale prices.

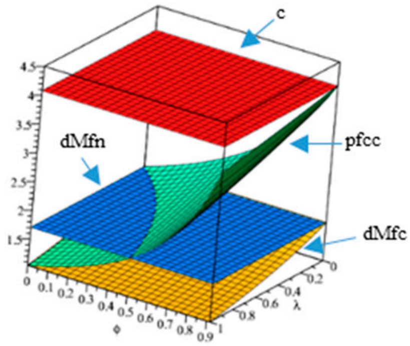

Figure 2. Effects of fairness concerns and profit-sharing on product green degree.

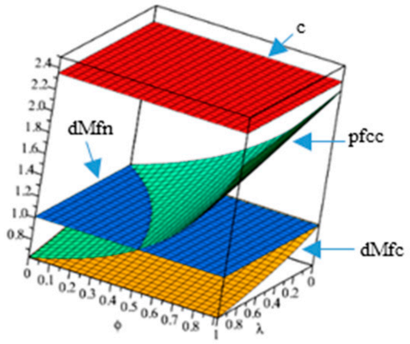

Figure 3. Effects of fairness concerns and profit-sharing on sales effort degree.

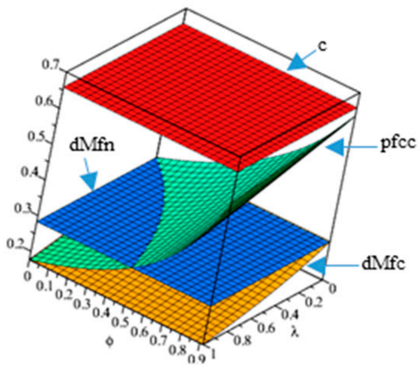

Figure 4. Effects of fairness concerns and profit-sharing on recycling rate.

As shown in Figures 5 and 6, it clear that the unit retail price and service level are both the best results in the centralized model. As M cares more about whether the distribution is fair, the retail price gradually increases, while the service level would gradually decrease. In addition, taking into account fairness concerns, the profit-sharing contract can make retail obtain more profits. When M's fairness concerns degree and profit-sharing ratio coefficient reach a certain value, the profit-sharing contract has a positive effect on green CLSC. Both the retail price and service level are gradually approaching to the equilibrium solution under centralized model. Comparing with the equilibrium solutions of M's fairness neutrality, the coordinated retail price is lower, while the R's service level is higher.

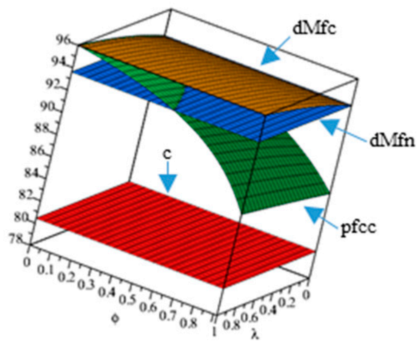

Figure 5. Effects of fairness concerns and profit-sharing on retail price.

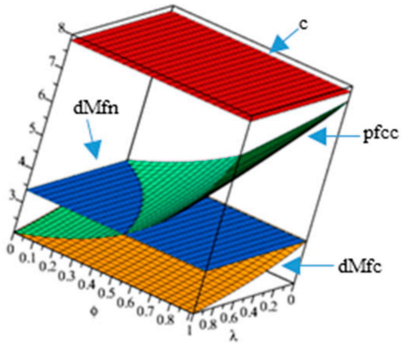

Figure 6. Effects of fairness concerns and profit-sharing on service level.

In Figures 7–11, it is clearly shown the centralized model is still optimal, where market demand and profits of all parties are the most effective. When M considerates fairness concerns, the profits of all parties would be affected, and the profits of the overall system would decline. However, M would gain more and more profits and obtain the main profits of the market. It can be further seen from the figures that the profit-sharing contract can effectively solve the problem of unfair profit distribution. When M's fairness concerns and profit-sharing ratio coefficient satisfy a certain condition, profit-sharing contracts can effectively disperse the negative effects of fairness concerns, which can make the system better. From Figure 9, R's profit gradually decreases with M's degree of fairness concerns increasing, when the profit-sharing proportion coefficient is higher than the certain value. When the R's profit under the coordination mechanism is less than that in the decentralized model with M's fairness concerns, it means that the combination of M's fairness concerns coefficient and profit-sharing proportion coefficient is not desirable, because the bargaining power of M is weak when its fairness concerns degree is low.

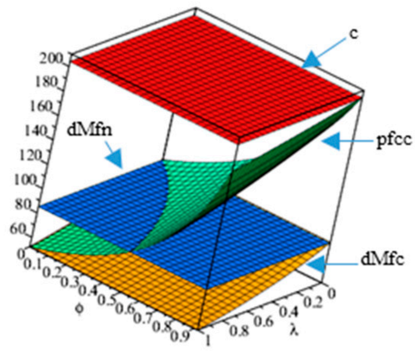

Figure 7. Effects of M's fairness concerns on market demand.

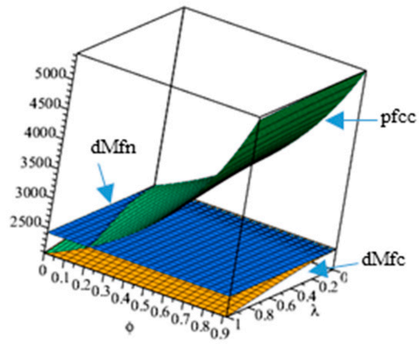

Figure 8. Effects of M's fairness concerns on M's profits.

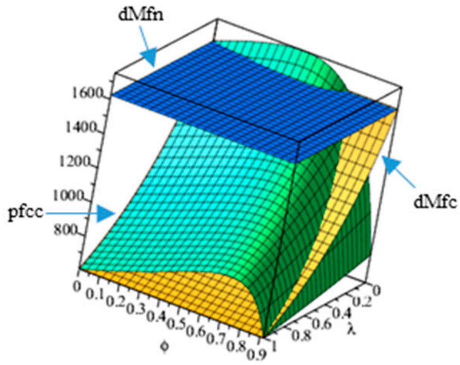

Figure 9. Effects of M's fairness concerns on R's profit degree.

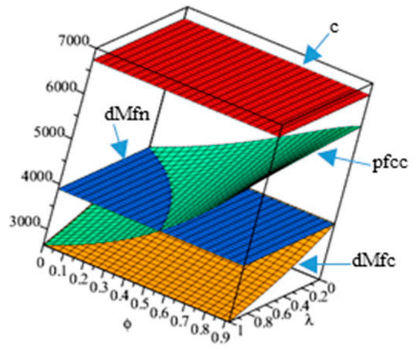

Figure 10. Effects of M's fairness concerns on system profit.

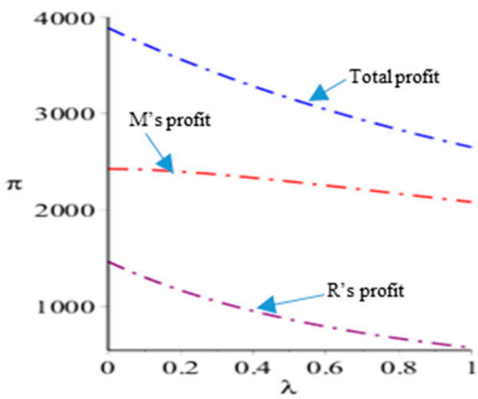

Figure 11. Impact of M's fairness concerns on profits of both parties and system.

7. Conclusions

To reduce resource loss and environmental pollution, green CLSC has become a hot issue in reality. In actual operation of green CLSC. manufacturers would pay attention to the fairness of profit distribution when making sales effort. Therefore, it is an important issue to improve the economic and environmental benefits of the green CLSC considering manufacturers' sales effort and fairness concerns. This paper researched the green CLSC, where three models were discussed by considering M's fairness neutrality and fairness concerns. The equilibrium solutions in different models were compared and analyzed. A profit-sharing contract was used to coordinate the decentralized model. The results were verified by numerical simulation. The following conclusions were obtained: (1) The retail price, product green degree, sales effort degree, service level, recycling rate, market demand and system profit are all optimal in the centralized model because decentralized decisions would exacerbate the double marginalization of the supply chain. (2) M's fairness concerns would lead to a lower quality of green products, lower levels of sales effort and the decrease in the recycling rate of used products. R would reduce the level of service and increase the price of products to ensure its own profits. (3) Under the decentralized model with fairness concerns, the profits of M, R and the supply chain system decrease with the fairness concerns coefficient; however, M can obtain a greater percentage of profits. When M believes that the profit distribution is unfair, the M would sacrifice its own interests to punish retailers and achieve fairness in profit distribution. (4) When the profit-sharing proportion coefficient satisfies a certain condition, the green CLSC can be effectively coordinated. R, as a party who shares the profits, would consider the most favorable sharing ratio of own profits under the premise of compensating M's profits.

According to the above findings, the following management implications are obtained: (1) Manufacturers, as leaders, should actively contact retailers and call for win–win cooperation. Therefore, manufacturers should take the initiative to cooperate with retailers and promote the establishment of coordination mechanism to implement the sustainable and healthy development of green CLSC. (2) Retailers should not ignore manufacturers' fairness concerns. Retailers could respond to manufacturers' fairness concerns by improving service levels and lowering product prices. Retailers should closely contact the manufacturer and pay attention to manufacturers' psychology and decision. R could take measures to eliminate manufacturers' fairness concerns. If manufacturers' fairness concerns are eliminated, the retailers' profits increase significantly. (3) Profit-sharing contract could strengthen cooperation between manufacturers and retailers and promote the development of green CLSC. Enterprises in the green CLSC could draw on the contract mechanism in this paper and build an appropriate coordination contract to achieve a win-win situation.

In the theoretical implications, this paper incorporates manufacturers' fairness concerns and sales effort into green CLSC, which enriches research on green CLSC management. In the practical implications, this paper takes green CLSC as the research object. Considering manufacturers' sales efforts, a model is constructed with manufacturers' fairness concerns. The research provides useful information to researchers and practitioners for judgments and ultimately creates more sustainable decisions in green CLSC. However, this paper still has some limitations, which provide opportunities for future research. For example, the data used in the numerical simulations are from existing literature. In future research, real data from enterprises can be collected, and the numerical simulation results can be compared with the actual business conditions of enterprises to obtain more realistic guidance for decision-making in green CLSC. In addition, social aspects are not considered in the model. In future research, social aspects can be added to the model to study a sustainable green CLSC.

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Appendix A

Proof of Proposition 1. In the centralized model, M and R form an alliance, who jointly make decisions to enhance the overall greenCLSC system profits, and where decision variables are the retail price, product greenness, sales effort and service level. The Hesse matrix of profit function π^c of green CLSC system with respect to p, g, y, s in the centralized model is $\nabla^2\pi^c = \begin{bmatrix} -2b & k-b\theta(c_m-c_r-m) & l & \mu \\ k-b\theta(c_m-c_r-m) & -c_1+2k\theta(c_m-c_r-m) & l\theta(c_m-c_r-m) & \mu\theta(c_m-c_r-m) \\ l & l\theta(c_m-c_r-m) & -c_2 & 0 \\ \mu & \mu\theta(c_m-c_r-m) & 0 & -c_3 \end{bmatrix}$. It can be judged that the Hesse matrix is negative and that π^c is a concave function. Taking the first derivative of Equation (1) with respect to p, g, y and s, and obtaining $\frac{\partial\pi^c}{\partial p}=0$, $\frac{\partial\pi^c}{\partial g}=0$, $\frac{\partial\pi^c}{\partial y}=0$ and $\frac{\partial\pi^c}{\partial s}=0$, the optimal p, g, y and s can be respectively as follows: $y^{c*}=\frac{c_1c_3l(a_0-bc_m)}{A}$, $s^{c*}=\frac{\mu c_1c_2(a_0-bc_m)}{A}$, $p^{c*}=\frac{c_2c_3(a_0-bc_m)(c_1-\theta(c_m-c_r-m)(k+b\theta(c_m-c_r-m)))}{A}+c_m$ and $g^{c*}=\frac{c_2c_3(a_0-bc_m)(k+b\theta(c_m-c_r-m))}{A}$. Then $\beta^{c*}=\frac{c_2c_3\theta(a_0-bc_m)(k+b\theta(c_m-c_r-m))}{A}$ and $D^{c*}=\frac{bc_1c_2c_3(a_0-bc_m)}{A}$ can be obtained. Substituting p^{c*}, g^{c*}, y^{c*} and s^{c*} into Equation (1), the optimal profit of the green CLSC can be obtained: $\pi^{c*}=\frac{c_1c_2c_3(a_0-bc_m)^2}{2A}$. □

Appendix B

Proof of Proposition 2. Taking partial derivatives of the R's profit function with respect to p and s and solving the first-order conditions $\frac{\partial\pi_r^d}{\partial p}=0$ and $\frac{\partial\pi_r^d}{\partial s}=0$, the decision functions of $p^d=\frac{c_3(a_0+gk+bw+ly)-w\mu^2}{2bc_3-\mu^2}$ and $s^d=\frac{(a_0+gk-bw+ly)\mu}{2bc_3-\mu^2}$ are obtained, which are substituted into π_m^d. M's profit function is a strictly concave function with w, g and y. The first-order derivatives are equal to 0, and then the optimal decision functions of both parties can be obtained. □

Appendix C

Proof of Proposition 3. The first-order partial derivative of the function of wholesale price with respect to λ is solved: $\frac{\partial w_\lambda^{d*}}{\partial\lambda}=\frac{c_1c_2(a_0-bc_m)\left(2bc_3-\mu^2\right)\left(c_3\left(bc_2(2c_1-k\theta(c_m-c_r-m))-c_1l^2-c_2k^2\right)-c_1c_2\mu^2\right)}{b(C+\lambda c_1c_2(2bc_3-\mu^2))^2}$. Because of $c_3\left(bc_2(2c_1-\theta(c_m-c_r-m)(k+b\theta(c_m-c_r-m)))-c_1l^2-c_2k^2\right)-c_1c_2\mu^2>0$, $2bc_3-\mu^2>0$ and $c_3\left(bc_2(2c_1-k\theta(c_m-c_r-m))-c_1l^2-c_2k^2\right)-c_1c_2\mu^2>0$, $\frac{\partial w_\lambda^{d*}}{\partial\lambda}>0$ can be calculated.

The proofs of other functions are similar.

Because of $\frac{\partial g_{\lambda}^{d*}}{\partial \lambda} = -\frac{c_1 c_2^2 c_3 (a_0 - bc_m)(k + b\theta(c_m - c_r - m))(2bc_3 - \mu^2)}{(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$, $\frac{\partial g_{\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated.

Because of $\frac{\partial y_{\lambda}^{d*}}{\partial \lambda} = -\frac{c_1^2 c_2 c_3 l (a_0 - bc_m)(2bc_3 - \mu^2)}{(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$, $\frac{\partial y_{\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated.

Because of $\frac{\partial p_{\lambda}^{d*}}{\partial \lambda} = \frac{c_1 c_2 (a_0 - bc_m)(2bc_3 - \mu^2)(c_3(bc_2(c_1 - k\theta(c_m - c_r - m)) - c_1 l^2 - c_2 k^2) - c_1 c_2 \mu^2)}{b(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$, $\frac{\partial p_{\lambda}^{d*}}{\partial \lambda} > 0$ can be calculated.

Because of $\frac{\partial s_{\lambda}^{d*}}{\partial \lambda} = -\frac{c_1^2 c_2^2 \mu (a_0 - bc_m)(2bc_3 - \mu^2)}{(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$, $\frac{\partial s_{\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated.

Because of $\frac{\partial \beta_{\lambda}^{d*}}{\partial \lambda} = -\frac{c_1 c_2^2 c_3 \theta (a_0 - bc_m)(k + b\theta(c_m - c_r - m))(2bc_3 - \mu^2)}{(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$, $\frac{\partial \beta_{\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated.

Because of $\frac{\partial D_{\lambda}^{d*}}{\partial \lambda} = -\frac{b c_1^2 c_2^2 c_3 (a - bc_m)(2bc_3 - \mu^2)}{(C + c_1 c_2 (2bc_3 - \mu^2))^2}$, $\frac{\partial D_{\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated. □

Appendix D

Proof of Corollary 1. According to $\pi_{m\lambda}^{d*} = \frac{c_1 c_2 c_3 \begin{pmatrix} a_0 - \\ bc_m \end{pmatrix}^2 \begin{pmatrix} C + \\ 2\lambda c_1 c_2 (2bc_3 - \mu^2) \end{pmatrix}}{2(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$, $\pi_{r\lambda}^{d*} = \frac{c_1^2 c_2^2 c_3 \begin{pmatrix} a_0 - \\ bc_m \end{pmatrix}^2 \begin{pmatrix} 2bc_3 - \\ \mu^2 \end{pmatrix}}{2(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$ and $\pi_{\lambda}^{d*} = \frac{c_1 c_2 c_3 (a_0 - bc_m)^2 (C + c_1 c_2 (1 + 2\lambda)(2bc_3 - \mu^2))}{2(C + \lambda c_1 c_2 (2bc_3 - \mu^2))^2}$, Corollary 1 can be obtained by solving the partial derivative function, respectively.

Because of $\frac{\partial \pi_{m\lambda}^{d*}}{\partial \lambda} = -\frac{c_1^3 c_2^3 c_3 (a_0 - bc_m)^2 \lambda (-2bc_3 + \mu^2)^2}{(C + c_1 c_2 \lambda (2bc_3 - \mu^2))^3}$, $\frac{\partial \pi_{m\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated.

Because of $\frac{\partial \pi_{r\lambda}^{d*}}{\partial \lambda} = -\frac{c_1^3 c_2^3 c_3 (a_0 - bc_m)^2 (-2bc_3 + \mu^2)^2}{(C + c_1 c_2 \lambda (2bc_3 - \mu^2))^3}$, $\frac{\partial \pi_{r\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated.

Because of $\frac{\partial \pi_{\lambda}^{d*}}{\partial \lambda} = -\frac{c_1^3 c_2^3 c_3 (a_0 - bc_m)^2 (1 + \lambda)(-2bc_3 + \mu^2)^2}{(C + c_1 c_2 \lambda (2bc_3 - \mu^2))^3}$, $\frac{\partial \pi_{\lambda}^{d*}}{\partial \lambda} < 0$ can be calculated. □

Appendix E

Proof of Corollary 2. Comparing M's profit and R's profit, we can obtain $\frac{\pi_{m\lambda}^{d*}}{\pi_{r\lambda}^{d*}} = 1 + C + 2\lambda c_1 c_2 (2bc_3 - \mu^2) > 1$. Therefore, it can be calculated that $\pi_{m\lambda}^{d*} > \pi_{r\lambda}^{d*}$. □

Appendix F

Proof of Proposition 4. That $\frac{\partial p_{\lambda}^{d*}}{\partial \lambda} > 0$ can be obtained from proposition 3. When $\lambda = 0$, it can be calculated that $p_{\lambda}^{d*} = p^{d*}$. Therefore, there is $p_{\lambda}^{d*} > p^{d*}$. When $bc_3(2c_1 - k\theta(c_m - c_r - m)) - c_1\mu^2 > 0$, there is $p_{\lambda}^{d*} > p^{c*}$. Because of $p^{d*} > p^{c*}$ and $p_{\lambda}^{d*} > p^{d*}$, we can obtain $p_{\lambda}^{d*} > p^{d*} > p^{c*}$. Similarly, $s_{\lambda}^{d*} < s^{d*} < s^{c*}$, $D_{\lambda}^{d*} < D^{d*} < D^{c*}$ can also be proved.

That $\frac{\partial w_{\lambda}^{d*}}{\partial \lambda} > 0$ can be obtained from proposition 3. When $\lambda = 0$, it can be calculated that $w_{\lambda}^{d*} = w^{d*}$. Therefore, there is $w_{\lambda}^{d*} > w^{d*}$.

That $\frac{\partial g_{\lambda}^{d*}}{\partial \lambda} < 0$ can be obtained from proposition 3. When $\lambda = 0$, it can be calculated that $g_{\lambda}^{d*} = g^{d*}$. Therefore, there is $g_{\lambda}^{d*} < g^{d*}$. When $bc_3(2c_1 - k\theta(c_m - c_r - m)) - c_1\mu^2 > 0$, there is $g^{d*} < g^{c*}$. Because of $g_{\lambda}^{d*} < g^{d*}$ and $g^{d*} < g^{c*}$, we can obtain $g_{\lambda}^{d*} < g^{d*} < g^{c*}$. Similarly, $y_{\lambda}^{d*} < y^{d*} < y^{c*}$, $\beta_{\lambda}^{d*} < \beta^{d*} < \beta^{c*}$ can also be proved.

That $\frac{\partial \pi_{m\lambda}^{d*}}{\partial \lambda} < 0$ can be obtained from proposition 3. When $\lambda = 0$, it can be calculated $\pi_{m\lambda}^{d*} = \pi_{m}^{d*}$. Therefore, there is $\pi_{m\lambda}^{d*} < \pi_{m}^{d*}$. Similarly, $\pi_{r\lambda}^{d*} < \pi_{r}^{d*}$ and $\pi_{\lambda}^{d*} < \pi^{d*}$ can also be proved.

Comparing π^{d*} and π^{c*}, it is obvious that $\pi^{d*} < \pi^{c*}$. Thus, $\pi_{\lambda}^{d*} < \pi^{d*} < \pi^{c*}$ can be calculated. □

Appendix G

Proof of Proposition 5. The purpose of contract coordination is to improve the profits of all parties, so $\pi_{m\phi}^{d*} > \pi_{m\lambda}^{d*}, \pi_{r\phi}^{d*} > \pi_{r\lambda}^{d*}$ are satisfied. Therefore, the range of ϕ can be obtained by taking the intersection of inequality. If the partial derivative of retailer's optimal profit about ϕ is 0, i.e., $\frac{\partial \pi_{r\phi}^{d*}}{\partial \lambda} = 0$, the optimal profit-sharing ratio coefficient can be obtained. □

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