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Pricing Decisions in Closed-Loop Supply Chains with Peer-Induced Fairness Concerns

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Abstract: The importance of behavioral factors in the process of decision making is widely recognized in literature and practice. The aim of this paper is to examine the influence of collectors' multiple fairness concerns on pricing decisions in a closed-loop supply chain (CLSC), which consists of one manufacturer, one retailer, and two collectors. Specifically, the collectors are concerned with both distributional fairness and peer-induced fairness. By considering fairness concerns and selecting Nash bargain solution as the reference point of fairness distribution, this paper studies the equilibrium solution of Stackelberg game models in the CLSC with symmetrical and asymmetrical information of fairness concerns, respectively. The results show that in the former case, distributional fairness is always at the cost of sacrificing the manufacturer's profits, which is a means of gaining more benefits for the collectors. In the latter case, the profits of both the manufacturer and the collectors turn into a loss. No matter in which case, the collector who is concerned with both distributional and peer-induced fairness is always in a passive position. Generally speaking, whether the decision maker concerns fairness and whether it can be perceived by the CLSC members both impact the members' decision making. Additionally, the utilities of both the manufacturer and the collectors receive Pareto improvement under the proposed incentive contract.

Keywords: closed-loop supply chain; distributional fairness concern; peer-induced fairness concern; Nash Bargain

1. Introduction

To decrease resource exhaustion and environmental pollution, in recent years many countries have strengthened their environmental legislation and have promulgated a series of relative laws which require manufacturing enterprises to recycle their used products so as to advocate the concept of green production and consumption, such as [1–5]. However, an increasing number of enterprises have realized that recycling used products is lucrative and plays an important role in the sustainable development of enterprises. It not only can reduce environmental pollution and improve the enterprises' reputations, but also lower production cost, thereby enhancing their competitiveness [6–8]. Based on this background, under the pressure of environmental protection laws and the economic interests of recycling used products, recycling activities have been brought by a large number of enterprises into their development strategy; accordingly, they attach great importance to the recycling process. Many famous international companies such as IBM, Kodak, Compaq, Xerox, etc., are positively probing into effective recycling management modes, hoping to reduce their operation cost and improve their performance.

Compared with traditional economics hypothesis of rational humans, a group of behavioral scientists represented by Kahneman [9,10], found after constant exploration and verification that most people in reality are non-rational and are not only concerned with the fairness in their own interests but pay close attention to their related groups' benefits. Sometimes they even give up their benefits for a fair distributional result, that is, their fairness concerns. For example, Scheer et al. [11] made a survey of approximately 417 car dealers in America and 289 car dealers in the Netherlands and found that the dealers paid excessive attention to distributional fairness when trading with business partners. The same case occurred in the Wanji trade of Xuzhou in China in 2010, where the downstream distributors ceased their cooperation with Procter & Gamble, as they thought the price of the products was unfair. Fairness concerns, which are a kind of peculiar behavior preference of people, have created a topic worthy of inquiry in the behavioral science field. Studies on the behavioral science-based supply chain have formed a new wave of research internationally [12,13].

In the one-to-many closed-loop supply chain (CLSC) system, distributional fairness is another concern, in addition to self-interest and fairness among longitudinal decision makers. Many studies have been conducted on this topic [14,15]. Furthermore, decision-makers are also concerned with profit differences among horizontal peers, which is peer-induced fairness [16–19].

It is noteworthy that nearly all of the previous studies were concerned with whether or not the production cost, the recycling cost, and the wholesale price information were symmetrical [20]. These studies barely concentrated on the symmetry of the information regarding fairness concerns. It is worth exploring whether information about fairness concerns will change the equilibrium solution in a CLSC.

To investigate the influence of fairness concerns as well as its symmetry and asymmetry on CLSC decisions, this paper concentrates on a CLSC composed of one manufacturer, one retailer, and two collectors. Assume that collector 1 is only concerned with distributional fairness, while collector 2 is concerned with both distributional fairness and peer-induced fairness. The Nash bargaining solution acts as a reference point for distributional fairness concerns, and collector 2 uses the revenue of collector 1 as a reference point for peer-induced fairness concerns. Based on observations from current practice and the extant literature, three models are considered: (1) CLSC model under fairness neutral, (2) CLSC model with symmetrical information of fairness concerns, and (3) CLSC model with asymmetrical information of fairness concerns.

More specifically, the following issues are mainly studied in this paper.

- The equilibrium solution of CLSC models in the cases of symmetrical and asymmetrical information of fairness concerns.
- The influence of distributional fairness concerns coefficient and peer-induced fairness concerns coefficient on the equilibrium solution of CLSC models.
- How to design an incentive contract to achieve Pareto improvement in the CLSC.

The main contributions of this paper are as follows. First, we consider multiple fairness concerns of collectors in a CLSC and examine the influence of collectors' multiple fairness concerns on pricing decision. Second, we characterize the equilibrium solution of CLSC models with symmetrical and asymmetrical information of fairness concerns. Third, to realize the system utility maximization, a two-part tariff contract is put forward to achieve Pareto improvement in the CLSC.

The rest of the paper is organized as follows. Section 2 talks about the relevant literature review. Section 3 constructs several basic models to obtain the equilibrium state in the discrete and centralized cases. Section 4 establishes a fairness-concerned utility system based on Nash bargain theory and studies the equilibrium solution when there is symmetrical and asymmetrical information. An incentive contract is given in Section 5. Section 6 is about the numerical research and Section 7 concludes the paper. All proofs are provided in the Appendix A.

2. Literature Review

This paper draws on and contributes to several streams of literature, each of which we review below.

In recent years, many researchers have questioned the basic assumptions of rational economic men and proved that the behavior of decision makers will be influenced by social preferences [21,22]. Fehr and Schmidt [12] made a pioneering contribution to modeling fairness as self-centered inequity aversion. Cui et al. [23] analyzed the problems such as the optimal pricing decisions of supply chain members and the coordination of the members' revenue under fairness preference. Mathies et al. [24] studied how customers made choices under the impact of fairness-concerned behaviors. Han et al. [25] discussed the optimal pricing decisions when considering members' fairness concerns in a CLSC. Ma [26] analyzed the optimal pricing decisions in CLSC models with four different collection channel structures when taking retailer's fairness concerns and market efforts into account. Unfortunately, all of the literature above directly took the other party's profits or a multiplier of the profits as reference points when considering absolute fairness. However, the strength and the contributions of the two sides are different, so selecting the reference points is concerned with the bargain ability of the two parties. Additionally, the previous literature only considered distributional fairness concerns. In contrast, in this paper, both the collector's distributional fairness concerns and peer-induced fairness concerns are considered.

The theoretical and practical study by Fehr and Gette [27] showed that the longitudinal and the horizontal fairness concerns had a weak influence on a one-off interaction while repeated interactions would amplify the fairness concerns for the results, but the authors did not introduce the concept of peer-induced fairness concerns. The concept of "peer-induced fairness concerns" was first proposed by Ho and Su [16], and through experiments they verified the existence of fairness concerns. Additionally, the degree of peer-induced fairness concerns is roughly twice that of distributional fairness concerns. Therefore, peer-induced fairness concerns are supposed to draw more attention. Ho et al. [28] showed that the second retailer in the peer-induced fairness concern is at a disadvantage compared with the first one, who is only concerned with distributional fairness concerns. Shi and Zhu [17] simultaneously introduced distributional fairness concerns and peer-induced fairness concerns to the studies on forward supply chain. The equilibrium results indicate that the retailer who is concerned with both types of fairness will get a higher wholesale price and that peer-induced fairness will put him at a disadvantage. However, all the literature mentioned above considered symmetrical information of fairness concerns. In contrast, based on the Nash bargain fairness concerns utility, this paper tries to introduce peer-induced fairness concerns to CLSC models, and consider the impact of asymmetrical information of fairness concerns on CLSC decisions.

It is well-known that in most cases the wholesale price contract cannot achieve coordination of a supply chain. However, in reality, it is easy to perform and the supervision cost is low, so wholesale price contracts become favored by a large number of practitioners. Accordingly, studying wholesale price contracts under fairness preference will provide more guiding significance for the supply chain practice. The present wholesale price contracts under fairness preference are performed primarily from two aspects. First, when the fairness preference information is symmetrical, Cui et al. [23] found that under the linear demand condition when the fairness preference of members was considered, only setting a higher wholesale price than the cost can achieve both the coordination of a supply chain and the Pareto improvement of the system. The same conclusion was acquired under the nonlinear demand condition by Caliskan-Demirag et al. [29,30], who found that the supplier could offer wholesale price contracts to achieve coordination of a supply chain only if one member of the supply chain has a fairness preference. Du [31] proved that a fairness preference could change the equilibrium solutions, and under certain wholesale price conditions, the wholesale price contracts could achieve competitive coordination of a supply chain. Zhang and Ma [32] studied the impact of fairness preference on pricing decisions in a supply chain. Second, in the case of asymmetrical fairness preference information, Katok et al. [33] found that with wholesale price contracts, asymmetrical fairness preference information can lead to the decline of supply chain performance. However, Pavlov and Katok [34] noted that when the fairness concerns belonged to private information, the coordination of a supply chain cannot be achieved. Through a mass of experimental data by Katok et al. [35] showed that the fairness concerns behaviors of supply chain members had a great influence on the formation of contracts to achieve coordination. Therefore, the concerns of supply chain members for fairness preference information cannot be neglected.

Compared with studies on contract coordination in a forward supply chain, there has recently been less literature about studies on contract coordination in reverse and CLSCs [36,37]. Some scholars have adopted benefit-sharing contracts to achieve coordination of a reverse supply chain. For instance, Zeng [38] designed a benefit-sharing coordination mechanism for a three-stage reverse supply chain. In a similar way, Li et al. [39] designed a cost-sharing contract. They showed that this kind of contract not only can maximize the profits of reverse supply chain but also boost the interests of each supply chain member.

In addition, scholars have adopted some other contracts to achieve coordination of a reverse supply chain. For instance, Huang et al. [40] designed a quantity-discount contract to deal with profit conflict problems that arose from the reverse supply chain. The research indicates that the profits of the retailer and the supplier are both increased by a properly designed contract parameter. Xu [41] established a dynamic Stackelberg game model for the reverse supply chain of waste electric products and offered a kind of alternative contract to achieve coordination of the supply chain. The coordination of CLSC is studied under static and dynamic context by [42] and [43], respectively. Based on the previous literature, this paper attempts to design a two-part tariff contract mechanism for achieving Pareto improvement in a CLSC.

In summary, most research on the impact of fairness concerns on supply chain decision-making is based on the assumption that fairness concerns information is symmetrical, and that decision makers only focus on distributional fairness. To address this gap, in this paper the Stackelberg game is used to prove that under asymmetry information, both the profits of the manufacturer and the collectors turn into a loss. No matter in which case, the collector who concerns distributional and peer-induced fairness together is always in a passive position. We also find that the two kinds of fairness concerns have counteractions to the decisions of all the CLSC members. The distributional fairness sacrifices the manufacturer's interests to benefit the collectors, while peer-induced fairness sacrifices the collectors' interests to benefit the manufacturer. Besides, both the utilities of the manufacturer and the collectors receive Pareto improvement under the proposed incentive contract. Our results can provide guidance for enterprises on CLSC decisions.

3. Pricing Decisions in A CLSC Under Fairness Neutral

3.1. Problem Description

A CLSC that consists of one manufacturer M, one retailer R, and two collectors T_1 and T_2 is considered in this paper. Assume that the two collectors are homogeneous and perform their collection activities in a mutually independent market so that the collection quantity is determined by the collection price. The new products and the remanufactured products are completely fungible, and their sale prices are the same, which means that the products made from raw materials and used products are homogeneous. The manufacturer is the Stackelberg leader of the channel, while the retailer and the collectors are followers. The retailer and the manufacturer are fairness-neutral, while the collector is fairness-concerned and concerns the profits of both the manufacturer and the peer collector. Therefore, the paper analyzes the influence of fairness-concerned behaviors on CLSC decisions.

3.2. Parametric Hypothesis and Symbols

For convenience, suppose the wholesale price is w, the retail price, p. The marketing demand $D(p)$ is a deterministic decreasing function of p, expressed as $D(p) = a - bp$, in which a is the potential capacity of the market and b is the sensitivity coefficient of the price. c_m denotes the cost of the new products produced by raw materials. The cost of remanufacturing is presented as c_r, so unit cost saving of remanufacturing is $\Delta = c_m - c_r$. The return rate of used products is r, and $A_i (i = 1, 2)$ expresses the collection price of the collector i. B_i expresses the transfer price given to the collector by the manufacturer. To assure all parties are profitable, it needs to meet $A_i < B_i < \Delta$. Let G_i denote the collection quantity of the collector i, $G_i = h_i + A_i (i = 1, 2)$. h_i denotes the quantity of used products collected in the case where the collector pays no collection cost. For convenience, let $G = G_1 + G_2$ and $h = h_1 + h_2$. In addition, the subscripted "*sc*" expresses the decisions of the supply chain. The superscript "*" denotes the optimal solution, the subscripted "*o*" presents the centralized decision-making and the subscripted "*f*" expresses fairness concerns. The superscripts "SI, AI" respectively present symmetrical and asymmetrical information. π_M, π_R and π_{T_i} denote the profit of the manufacturer, the retailer and the collector i, respectively. u_M, u_R and u_{T_i} express respectively the utility of the manufacturer, the retailer and the collector i. For example, $u_{T_i}^{SI-f*}$ expresses the optimal utility when the collector considers fairness concerns under symmetrical information.

3.3. Optimal Decisions in a CLSC under Fairness Neutral

3.3.1. Centralized Decision Case

As known, the supply chain is the most effective under the centralized mode. So, the utility under centralized decision-making is as the benchmark of operation efficiency under different incentive contracts. In this mode, the manufacturer, the retailer and the collectors cooperate to determine the optimal retail price and collection prices to maximize the entire supply chain utility.

Let A_{io}, w_o, and p_o symbolize the collection price of used products, the wholesale price, and the retail price, respectively. The system profit π_{sco} of the CLSC is as follows:

$$\max_{p_o, A_{io}} \pi_{sco} = (p_o - c_m)D + \sum_{i=1}^{2} (\Delta - A_{io})G_{io}. \tag{1}$$

The manufacturer, the retailer, and the collector are all fairness neutral, so the expected profit of the supply chain can be presented as expected utility, i.e., $\pi_{sco} = u_{sco}$, and p_o and A_{io} are decision variables.

From Equation (1), it can be referred that the Hessian matrix of the CLSC profit π_{sco} is negative definite, that is, π_{sco} is strictly concave in p_o and A_{io}. With the first order condition, the optimal decision of the CLSC is:

$$p_o^* = \frac{a + bc_m}{2b}, \; A_{io}^* = \frac{\Delta - h_i}{2}. \tag{2}$$

Furthermore, it can be figured out the return rate in the CLSC is as follows:

$$r_{sco}^* = \frac{2\Delta + h}{a - bc_m}. \tag{3}$$

3.3.2. Decentralized Decision Case

In the decentralized decision case, the manufacturer, the retailer, and the collector are all independent decision makers, each of them makes efforts to achieve their own maximal utility. Assume that the manufacturer is the Stackelberg leader. The manufacturer first sets the wholesale price of new products w and the transfer price of used products B_i, then the retailer sets the sale price p according to the wholesale price w, while the collectors set their collection price A_i according to the transfer price B_i. Therefore, the profits of CLSC members are as follows.

$$\max_{B_i, w} \pi_M = (w - c_m)D + \sum_{i=1}^{2} (\Delta - B_i)G_i. \tag{4}$$

$$s.t.\begin{cases} \max\limits_{p} \pi_R = (p-w)D \\ \max\limits_{A_1} \pi_{C1} = (B_1 - A_1)G_1 \\ \max\limits_{A_2} \pi_{C2} = (B_2 - A_2)G_2 \end{cases}. \tag{5}$$

With the backward induction, we can obtain:

$$w^* = \frac{a+bc_m}{2b},\ B_i^* = \frac{\Delta - h_i}{2},\ p^* = \frac{3a+bc_m}{4b},\ A_i^* = \frac{\Delta - 3h_i}{4}. \tag{6}$$

The return rate of the CLSC is:

$$r^* = \frac{2\Delta + h}{a - bc_m}. \tag{7}$$

Corollary 1. *$p_o^* > p^*$, $D_o^* > D^*$, $A_{io}^* > A_i^*$, $G_o^* > G^*$, $r_o^* = r^*$ and $u_{sco}^* > u_{sc}^*$.*

Corollary 1 suggests that because of the influence of double marginalization, the goals of all the CLSC members are to maximize their own utilities, which usually contributes to lower supply chain performance. When the manufacturer sets the transfer price without considering the collectors' utility, the influence of double marginalization can make the collectors cut the transfer price. Accordingly, the collection quantity of used products is reduced, which leads to the loss of CLSC efficiency. But the decrease of collection quantity is in proportion to that of demand quantity, so the return rate is unchanged.

4. Pricing Decisions in a CLSC with Fairness Concerns

4.1. Reference Framework of Nash Bargain Fairness Concerns

Assume that in the CLSC, the retailer is fairness neutral and other members are distributional fairness concerned. Moreover, collector 2 has extra tendency to peer-induced fairness concerns. So, there are two rounds in the Stackelberg game among them.

In the first round of game, the manufacturer first fixes the wholesale price w and the transfer price B_1. According to the manufacturer's decision, the retailer and collector 1 set the sale price p and the collection price A_1. At this time, the utilities of the manufacturer and the collector 1 are expressed as follows:

$$u_{M,1} = \pi_{M,1} - \lambda_M(\overline{\pi}_{M,1} - \pi_{M,1}),\ u_{T_1} = \pi_{T_1} - \lambda_T(\overline{\pi}_{T_1} - \pi_{T_1}). \tag{8}$$

In Equation (8), $(\overline{\pi}_{T_1}, \overline{\pi}_{M,1})$ presents the justice perception solutions of collector 1 and the manufacturer in the first round game, and there exists:

$$\overline{\pi}_{T_1} + \overline{\pi}_{M,1} = \pi_{T_1} + \pi_{M,1} = \pi_1. \tag{9}$$

By constructing Nash bargain model, it depicts the fairness reference solutions of the manufacturer and the collector. When the manufacturer's or the collector's profits are larger than Nash solution, the utility increases; otherwise, it decreases. The Nash bargain fairness reference solutions take the ability and the contribution of the supply chain members into account, which emphasizes the relative fairness instead of absolute fairness. Therefore, the Nash bargain fairness reference solutions are closer to the actual situations and it solves the limitation of the previous studies that only concern absolute fairness.

By calculation, the Nash bargain fairness reference solution is:

$$\overline{\pi}_{T_1} = \frac{1+\lambda_T}{2+\lambda_M+\lambda_T}\pi_1,\ \overline{\pi}_{M,1} = \frac{1+\lambda_M}{2+\lambda_M+\lambda_T}\pi_1. \tag{10}$$

By replacing Equation (10) into Equation (8), we get:

$$u_{T_1} = (1+\lambda_T)(\pi_{T_1} - \frac{\lambda_T}{2+\lambda_M+\lambda_T}\pi_1),\ u_{M,1} = (1+\lambda_M)(\pi_{M,1} - \frac{\lambda_M}{2+\lambda_M+\lambda_T}\pi_1). \quad (11)$$

When the manufacturer is fairness neutral, that is $\lambda_M = 0$.

$$u_{T_1} = (1+\lambda_T)[\frac{2}{2+\lambda_T}\pi_{T_1} - \frac{\lambda_T}{2+\lambda_T}\pi_{M,1}],\ u_{M,1} = \pi_{M,1}. \quad (12)$$

In the second round of game, collector 2 concerns not only the manufacturer's interests but also the collector 1's interests. It is clear for collector 2 to know the collector 1's actual profits in the first round of the game. Because of the homogeny of the two collectors, the collector 1's actual profit is the basis for collector 2 to compare. If the collector 2's profit is higher than the collector 1's, the utility of the former increases; otherwise, it decreases. In this round of game, the manufacturer provides collector 2 with the transfer price B_2. Accordingly, collector 2 makes his own collection price A_2. At this time, the utilities of collector 2 and the manufacturer are expressed respectively as follows:

$$u_{T_2} = \pi_{T_2} - \lambda_T(\overline{\pi}_{T_2} - \pi_{T_2}) - \theta(\pi_{T_1} - \pi_{T_2}),\ u_{M,2} = \pi_{M,2} - \lambda_M(\overline{\pi}_{M.2} - \pi_{M,2}). \quad (13)$$

where $\theta(\theta > 0)$ is the peer fairness concerns coefficient of collector 2, $(\overline{\pi}_{T_2}, \overline{\pi}_{M,2})$ represents the fairness perception solutions of collector 2 and the manufacturer in the second round of game, and it meets $\overline{\pi}_{T_2} + \overline{\pi}_{M,2} = \pi_{T_2} + \pi_{M,2} = \pi_2$. By calculation, the Nash bargain fairness perception solution is:

$$\overline{\pi}_{T_2} = \frac{\pi_2(1+\theta+\lambda_T) + \theta\pi_{T_1}(1+\lambda_M)}{2+\lambda_M+\lambda_T+\theta\lambda_M+2\theta},\ \overline{\pi}_{M2} = \frac{(1+\lambda_M+\theta\lambda_M+\theta)\pi_2 - (\theta+\theta\lambda_M)\pi_{T_1}}{2+\lambda_M+\lambda_T+\theta\lambda_M+2\theta}. \quad (14)$$

By placing $(\overline{\pi}_{T_2}, \overline{\pi}_{M,2})$ into the utilities of collector 2 and the manufacturer, it becomes:

$$u_{T_2} = (1+\lambda_T+\theta)\pi_{T_2} - \theta\pi_{T_1} - \lambda_T\frac{(1+\lambda_T+\theta)\pi_2 + (\theta+\theta\lambda_M)\pi_{T_1}}{2+\lambda_M+\lambda_T+\theta\lambda_M+2\theta}, \quad (15)$$

$$u_{M,2} = (1+\lambda_M)\pi_{M,2} - \lambda_M\frac{(1+\lambda_M+\theta\lambda_M+\theta)\pi_2 - (\theta+\theta\lambda_M)\pi_{T_1}}{2+\lambda_M+\lambda_T+\theta\lambda_M+2\theta}. \quad (16)$$

When the manufacturer is fairness neutral, that is $\lambda_M = 0$.

$$u_{T_2} = \frac{1+\theta+\lambda_T}{2+2\theta+\lambda_T}[2(1+\theta)\pi_{T_2} - 2\theta\pi_{T_1} - \lambda_T\pi_{M,2}],\ u_{M,2} = \pi_{M,2}. \quad (17)$$

The two rounds of game are associated with each other. In the first round, the transfer price B_1 offered by the manufacturer makes a difference to the collector 1's profit, and influences peer-induced fairness reference solution of collector 2 simultaneously. Therefore, the transfer price B_1 also affects collector 2's decision in the second round of game. The following sections use the backward induction to figure out the optimal pricing decisions of the CLSC.

4.2. Optimal Pricing Decisions under Symmetrical Information of Fairness Concerns

No matter in the first or the second round of game, when the collectors consider distributional fairness concerns under symmetrical information, the manufacturer also takes the collector's distributional fairness concerns into consideration when making decisions and the coefficient λ_T is common knowledge.

By using the backward induction, in the second round of game collector 2 chooses the collection price A_2^{SI-f} to maximize his utility $u_{T_2}^{SI-f}$. And the optimal collection price A_2^{SI-f} is:

$$A_2^{SI-f*} = \frac{[2(1+\theta)+\lambda_T]B_2^{SI-f} - \lambda_T\Delta - 2(1+\theta)h_2}{4(1+\theta)}. \quad (18)$$

It can be seen from Equation (18), the collector 2's optimal collection price is affected by the manufacturer's transfer price B_2^{SI-f}, the collection quantity of used products h_2 gained by collector 2 without paying any collection cost, the distributional fairness concerns coefficient λ_T between collector 2 and the manufacturer, and the peer-induced fairness concerns coefficient θ.

In the first round of game, collector 1 chooses the collection price A_1^{SI-f} to maximize his utility $u_{T_1}^{SI-f}$, and the optimal collection price A_1^{SI-f} is:

$$A_1^{SI-f*} = \frac{(2+\lambda_T)B_1^{SI-f} - \lambda_T\Delta - 2h_1}{4}. \tag{19}$$

It can be seen from Equation (19), A_1^{SI-f*} is influenced by the transfer price B_1^{SI-f}, the collection quantity of used products h_1 gained by collector 1 without paying any collection cost, and the distributional fairness concerns coefficient λ_T.

Because of the fairness neutral, the manufacturer always pursues own profit maximization, that is, $\pi_M^{SI-f} = u_M^{SI-f}$. And the wholesale price w is the same with that when the collectors are fairness concerns.

In the second round of game, the manufacturer chooses the transfer price B_2^{SI-f} to maximize the utility $u_{M,2}^{SI-f}$. While in the first round of game, the manufacturer chooses the transfer price B_1^{SI-f} to maximize the utility $u_{M,1}$. In a similar way, we can get:

$$B_2^{SI-f*} = \frac{\lambda_T\Delta + (1+\theta)(\Delta - h_2)}{2+2\theta+\lambda_T}. \tag{20}$$

$$B_1^{SI-f*} = \frac{(1+\lambda_T)\Delta - h_1}{2+\lambda_T}. \tag{21}$$

By replacing Equations (20) and (21) into Equations (18) and (19), the optimal prices of the two collectors are:

$$A_1^{SI-f*} = \frac{\Delta - 3h_1}{4},\ A_2^{SI-f*} = \frac{\Delta - 3h_2}{4} \tag{22}$$

Corollary 2. $\frac{\partial B_1^{SI-f*}}{\partial \lambda_T} > 0$, $\frac{\partial B_2^{SI-f*}}{\partial \lambda_T} > 0$, *and* $\frac{\partial B_2^{SI-f*}}{\partial \theta} < 0$.

Corollary 2 shows that under symmetrical information of fairness concerns, the transfer price changes in the same direction with distributional fairness concerns, and changes in the opposite direction with peer-induced fairness concerns. This indicates that distributional fairness concerns are beneficial to the collectors at the expense of the manufacturer, while the collector's peer-induced fairness concerns are of benefit to the manufacturer, but puts himself at a disadvantage.

Corollary 3. $B_i^{SI-f*} > B_i^*$, $\frac{\partial (B_i^{SI-f*} - B_i^*)}{\partial \lambda_T} > 0$, $i = 1, 2$.

Corollary 3 suggests that under symmetrical information of fairness concerns, the manufacturer will consider the fairness concerns of the collectors. By comparison, the transfer price under fairness concerns is always higher than that under the fairness neutral, which means that the manufacturer will deliver part of his profits to the collectors, and raise the transfer price. Furthermore, the difference between them also increases with the increase of the distributional fairness concerns coefficient. Therefore, if the collector devotes more distributional fairness concerns, the transfer price will be higher.

Corollary 4. *When* $h_1 = h_2 = \frac{h}{2}$, $B_1^{SI-f*} > B_2^{SI-f*}$.

Corollary 4 indicates that under symmetrical information of fairness concerns, if the two independent markets are completely similar, the collector 1's transfer price offered by the manufacturer is higher than the collector 2's, which makes collector 2 on a sticky wicket. As is known from Corollary 2, because the manufacturer knows that peer-induced fairness concerns are beneficial, he will reduce the transfer price given to collector 2.

Corollary 5. $\frac{\partial \pi_M^{SI-f*}}{\partial \lambda_T} < 0$, $\frac{\partial \pi_M^{SI-f*}}{\partial \theta} > 0$.

Corollary 5 manifests that under symmetrical information of fairness concerns, with the increase of the collector's distributional fairness concerns coefficient, the manufacturer's profit decreases. It suggests the collector's distributional fairness concerns are at the expense of sacrificing the manufacturer's interests. But when collector 2 has peer-induced fairness concerns, which puts himself at a disadvantage, thus on the contrary, the peer-induced fairness concerns are beneficial to the manufacturer.

Corollary 6. $\frac{\partial \pi_{T_i}^{SI-f*}}{\partial \lambda_T} > 0, i = 1, 2$, $\frac{\partial \pi_{T_2}^{SI-f*}}{\partial \theta} < 0$.

Corollary 6 manifests that under symmetrical information of fairness concerns, the collector's profit changes in the same direction with the distributional fairness concerns coefficient, and changes in the opposite direction with the peer-induced fairness concerns coefficient. This is consistent with the previous conclusion.

Conclusion 1. Under symmetrical information of fairness concerns, the profit of the CLSC will not change with the distributional fairness concerns coefficient of the collectors, but be just reallocated between the collectors and the manufacturer. This is because the increased profits of the two collectors are exactly the same as the reduced profits of the manufacturer.

4.3. Optimal Pricing Decisions under Asymmetrical Information of Fairness Concerns

The collector considers fairness concerns, but the manufacturer thinks the collector is fairness neutral, so the fairness concerns information between the manufacturer and the collector is asymmetrical.

In the second round of game, for the CLSC system in which fairness-concerned information is asymmetrical, there exists the only equilibrium solution. And the optimal transfer price B_2^{AI-f*} and the optimal collection price A_2^{AI-f*} are as follows.

$$B_2^{AI-f*} = \frac{\Delta - h_2}{2},\ A_2^{AI-f*} = \frac{2(1+\theta)(\Delta - 3h_2) - \lambda_T(\Delta + h_2)}{8(1+\theta)}. \tag{23}$$

In the first round of game, the optimal transfer price B_1^{AI-f*} and the optimal collection price A_1^{AI-f*} are listed as follows.

$$B_1^{AI-f*} = \frac{\Delta - h_1}{2},\ A_1^{AI-f*} = \frac{2(\Delta - 3h_1) - \lambda_T(\Delta + h_1)}{8}. \tag{24}$$

Corollary 7. $\frac{\partial A_i^{AI-f*}}{\partial \lambda_T} < 0, i = 1,2$, $\frac{\partial A_2^{AI-f*}}{\partial \theta} > 0$.

Corollary 7 manifests that under asymmetrical information of fairness concerns, the collection price is inversely proportional to the distributional fairness coefficient. This is because the manufacturer does not take the collector's fairness concerns into account, which causes the collector to "punish" the manufacturer indirectly. What's more, the collector 2's collection price is in direct proportion to the peer-induced fairness coefficient, which means the more peer-induced fairness concerns collector 2 devotes, the more worried it is about lower profit than the peer collector feels. Therefore, he raises the collection price to increase collection quantities and thus boosting his incomes.

Corollary 8. *When* $h_1 = h_2 = \frac{h}{2}$, $A_1^{AI-f*} < A_2^{AI-f*}$.

Corollary 8 indicates that under asymmetrical information of fairness concerns, if the two independent markets are completely similar, the collector 2's collection price is higher than that of the collector 1. This is because collector 2 wants to keep himself in a more important position in the market, he will raise the collection price.

Conclusion 2. No matter whether the information on fairness concerns is symmetrical or asymmetrical, the collector 2's pricing decisions are in a passive position.

Corollary 9. $\frac{\partial r^{AI-f*}}{\partial \lambda_T} < 0$, $\frac{\partial r^{AI-f*}}{\partial \theta} > 0$.

Corollary 9 indicates that under asymmetrical information of fairness concerns, the more distributional fairness concerns the collector devotes, the lower the return rate is. But when collector 2 devotes more concerns about peer-induced fairness, in order to ensure his interest is not fewer than that of the peer collector, collector 2 is willing to sacrifice partial interests and enhance the collection price, thus improving the return rate of the CLSC.

Corollary 10. $\frac{\partial \pi_M^{AI-f*}}{\partial \lambda_T} < 0$, $\frac{\partial \pi_M^{AI-f*}}{\partial \theta} > 0$.

Corollary 10 suggests that under asymmetrical information of fairness concerns, with the increase of distributional fairness concerns, the manufacturer's profit decreases. This is because the manufacturer does not consider distributional fairness concerns of the collectors, thus the collectors will indirectly "revenge" the manufacturer by lowering the collection price, which will result in the lower CLSC efficiency and the lower profit of the manufacturer. Because of asymmetry information and the influence of double marginalization, both of the two sides regard the maximization of own profits as the goal, thus leading to the loss of CLSC efficiency. When collector 2 has peer-induced fairness concerns that puts him at a disadvantage, it is of good benefit to the manufacturer on the contrary.

Corollary 11. $\frac{\partial \pi_{T_i}^{AI-f*}}{\partial \lambda_T} < 0, i = 1, 2$, $\frac{\partial \pi_{T_2}^{AI-f*}}{\partial \theta} > 0$.

Corollary 11 is evident. Because of asymmetrical information, with the increase of the distributional fairness concerns coefficient, the collectors will reduce the collection prices, which leads to the decrease of the collection quantity and the profits. At the same time, owing to the increase of the peer-induced fairness concerns coefficient, the collectors will enhance the collection prices, which leads to the increase of the collection quantity and the profits.

Corollary 12. $A_i^{SI-f*} > A_i^{AI-f*}$, $\frac{\partial (A_i^{SI-f*} - A_i^{AI-f*})}{\partial \lambda_T} > 0, i = 1, 2$, $\frac{\partial (A_2^{SI-f*} - A_2^{AI-f*})}{\partial \theta} < 0$.

Corollary 12 is evident. Owing to asymmetrical information and the manufacturer's neglect of distributional fairness, the collectors will cut the collection prices, and this gap widens with the increase of the fairness concerns coefficient.

Corollary 13. $r^{SI-f*} > r^{AI-f*}$, $\frac{\partial (r^{SI-f*} - r^{AI-f*})}{\partial \lambda_T} > 0$, $\frac{\partial (r^{SI-f*} - r^{AI-f*})}{\partial \theta} < 0$.

Corollary 13 is the extension of Corollary 12.

5. An Incentive Contract under Symmetrical Information of Fairness Concerns

Under asymmetrical information, the manufacturer is hard to know the collectors' utility, so as to be difficult to achieve CLSC coordination. Consequently, this paper designs an incentive contract for a CLSC with symmetrical information of fairness concerns.

The systematic profits of the CLSC in the cases of collector's fairness neutral and fairness concerns are both lower than those in the case of centralized decision-making, and the CLSC performances have various levels of loss due to the influence of double marginalization. In this paper, we use a two-part tariff contract mechanism to achieve Pareto improvement of the CLSC.

Assume that the fixed charge the manufacturer takes from the collector i is F_i. And the superscript "t" symbolizes the decisions under the incentive contract.

$$\max \pi_M^t = (w^t - c_m)D^t + \sum_{i=1}^{2}(\Delta - B_i^t)G_i^t + F_1 + F_2. \tag{25}$$

$$s.t.\begin{cases} \pi_{T_i}^t = (B_i^t - A_i^t)G_i^t - F_i \\ u_{T_1}^t = (1+\lambda_T)\left[\frac{2}{2+\lambda_T}\pi_{T_1} - \frac{\lambda_T}{2+\lambda_T}\pi_{M,1}\right] \geq u_{T_1}^{SI-f*} & (IR1) \\ u_{T_2}^t = \frac{1+\lambda_T+\theta}{2+\lambda_T+2\theta}\left[2(1+\theta)\pi_{T_2}^t - 2\theta\pi_{T_1}^t - \lambda_T\pi_{M,2}^t\right] \geq u_{T_2}^{SI-f*} & (IR2) \\ \frac{\partial u_{T_i}^t}{\partial A_i^t} = 0 & (IC) \end{cases}. \tag{26}$$

Under the incentive contract offered by the manufacturer, there exists the only equilibrium solution. The optimal transfer price B_i^{t*}, the optimal collection price A_i^{t*}, and fixed cost F_i are respectively as follows.

$$B_i^{t*} = \Delta,\ A_i^{t*} = \frac{\Delta - h_i}{2}, i = 1, 2. \tag{27}$$

$$F_1^* = \frac{3(\Delta + h_1)^2}{8(2+\lambda_T)}, F_2^* = \frac{3(1+\theta)(2+\lambda_T)(\Delta + h_2)^2 - \lambda_T\theta(\Delta + h_1)^2}{8(2+\lambda_T)(2+2\theta+\lambda_T)}. \tag{28}$$

Corollary 14. $r^{t*} > r^{SI-f*}$, $\pi_M^{t*} > \pi_M^{SI-f*}$, $\pi_{T_i}^{t*} > \pi_{T_i}^{SI-f*}$.

Corollary 14 manifests that the proposed two-part tariff contract is effective, based on which profits of the manufacturer and the collectors are improved and the return rate increases, which also benefits environmental protection and sustainable development.

6. Numerical Analysis

As mentioned above, we suggest that the manufacturer establishes a two-part tariff contract to improve the efficiency of the CLSC. In this section, numerical examples are utilized to simultaneously prove the effectiveness of the two-part tariff contract and study the influence of fairness concerns on CLSC decisions.

Let the model parameters $a = 1000$, $b = 1$, $h_1 = h_2 = 10$, $c_m = 80$, $c_r = 40$, and $\Delta = 40$. The influence of distributional fairness concerns on CLSC system member profits is shown in Figure 1 ($\theta = 0.4$). Figure 1 suggests that whether or not the fairness concerns are symmetrical, the manufacturer's profits decrease with the increase of the fairness concerns coefficient (as shown in Figure 1c). When the information is symmetrical, the collector's profits are enhanced with the increase of the fairness concerns coefficient, which shows that fairness concern is a way to gain profits for collectors (as shown in Figure 1a,b). The decrease of the manufacturer's profit is the same with the increase for the collectors' profits, so the profit of the CLSC is unchanged.

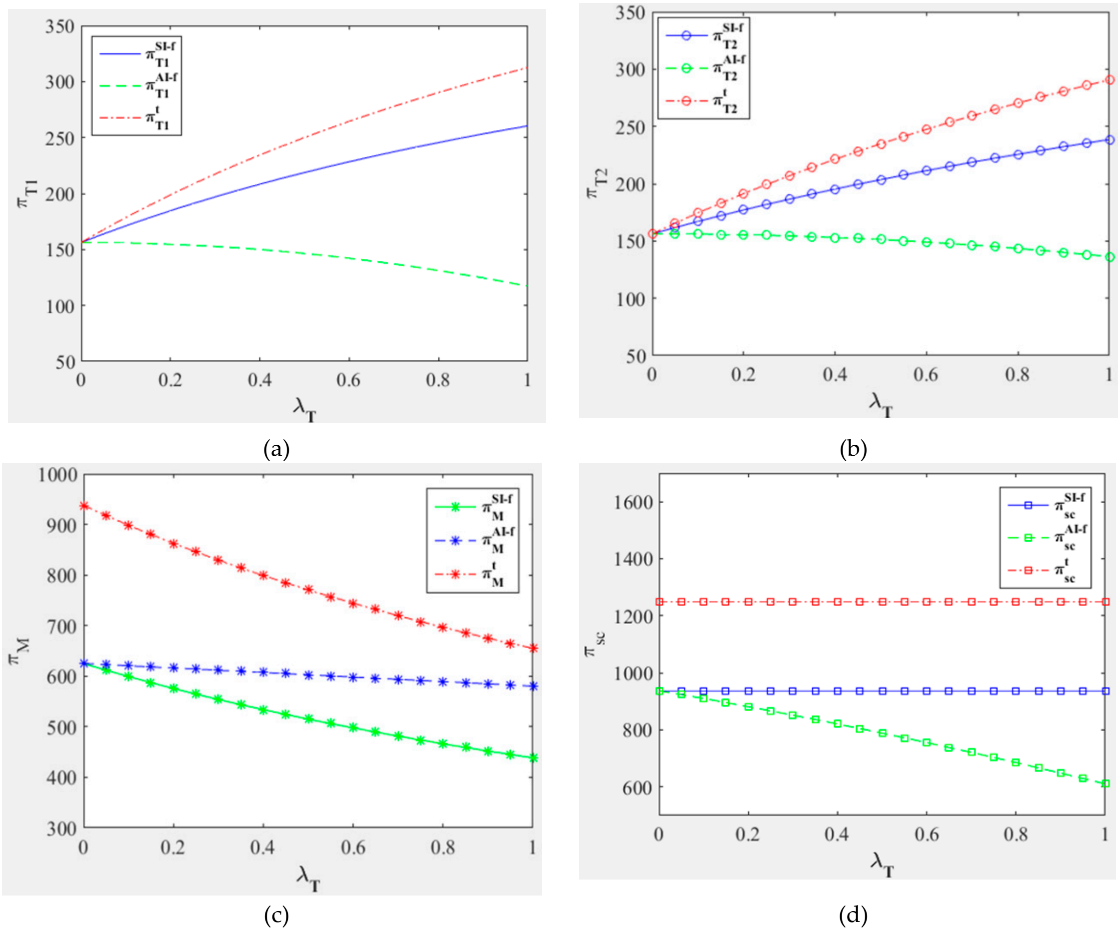


Figure 1. The influence of fairness concerns on CLSC system members' profits. (**a**) The influence of the fairness concerns on the collector 1's profits. (**b**) The influence of the fairness concerns on the collector 2's profits. (**c**) The influence of the fairness concerns on the manufacturer's profits. (**d**) The influence of the fairness concerns on the CLSC profits.

When the information is asymmetrical, the manufacturer ignores the collector's fairness concerns, which results in more fairness concerns from the collector about distribution. The collector will drastically cut the collection price to "punish" the manufacturer. All of these will lead to the decrease of the CLSC profit (as shown in Figure 1d) and the reduction of the return rate. Based on the two-part tariff contract, the profits of the manufacturer and the collectors both achieve Pareto improvement. At this time, the manufacturer will raise the transfer price to stimulate the collectors; then, the collectors will raise the collection price in return, thus improving the return rate of used products. This is beneficial for environmental protection and the increase of the CLSC profits.

When the information about distributional fairness concerns is symmetrical, the manufacturer is informed of the collector's fairness concerns. The manufacturer gives the collector more transfer payments, which increases the collectors' profit and collector 1's utility (as shown in Figure 2a). However, collector 2's transfer price offered by the manufacture is less than that offered to collector 1, thus collector 2's profit is enhanced but his utility is decreased (as shown in Figure 2b). From the analysis above, the manufacturer's utility also decreases. As a result, the utility of the CLSC is reduced (as shown in Figure 2c). When the information regarding fairness concerns is asymmetric, the utilities of the manufacturer, the collectors, and the whole CLSC change in the opposite direction to the fairness concerns coefficient.

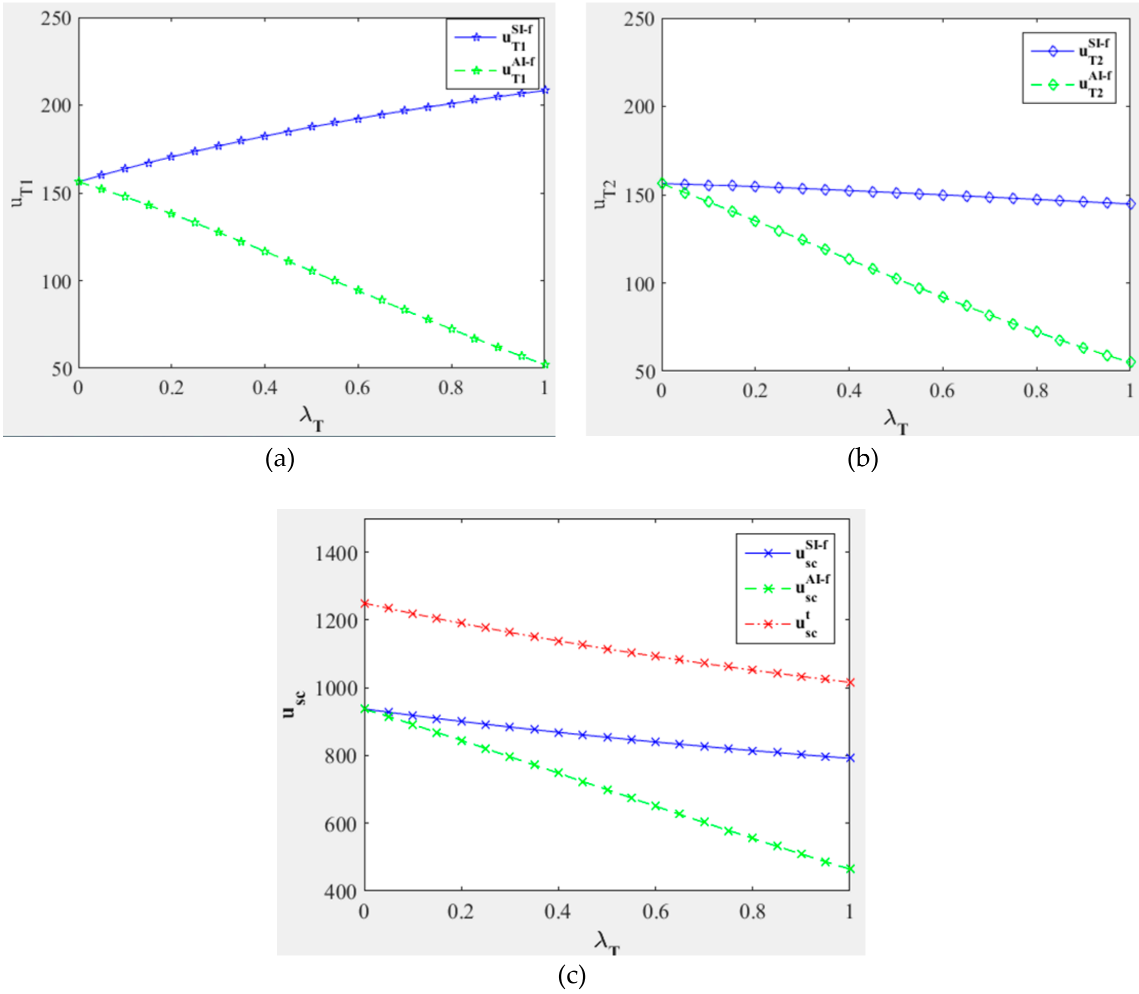
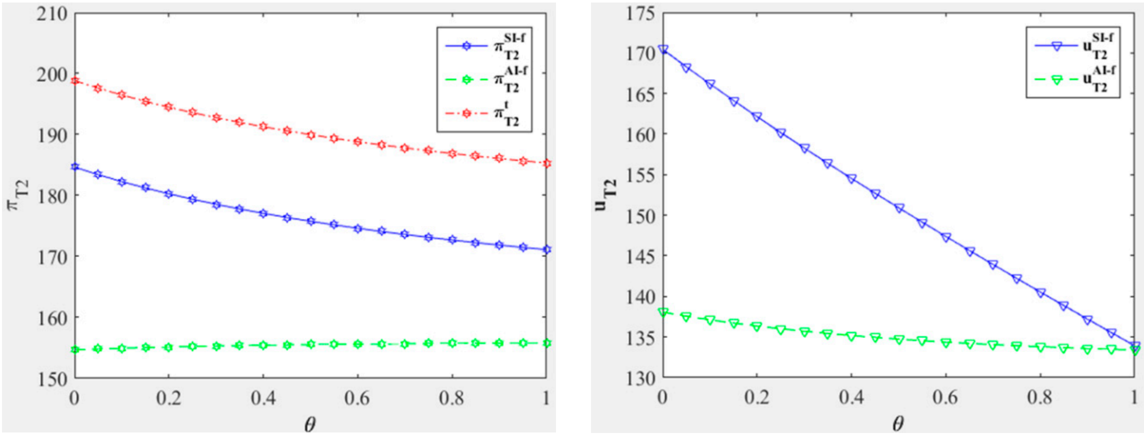


Figure 2. The influence of the distributional fairness concerns coefficient on CLSC system members' performance. (**a**) The influence of the distributional fairness concerns coefficient on the collector 1's performance. (**b**) The influence of the distributional fairness concerns coefficient on the collector 2's performance. (**c**) The influence of the distributional fairness concerns coefficient on the CLSC performance.

To analyze the influence of the peer-induced fairness concerns coefficient on CLSC decisions, assume that the collector's distributional fairness concerns coefficient remains unchanged ($\lambda_T = 0.2$). According to Figure 3, under symmetrical information, collector 2 is in a passive position because of his peer-induced fairness concerns. The transfer price of collector 2 given by the manufacturer is lower than that offered to collector 1, so with the increase in the peer-induced fairness concerns coefficient, collector 2's profit and utility are both reduced. In a situation of asymmetrical information, collector 2 enhances their income by raising the collection price to make his own profit no less than that of the peer collector's; thus, the profit increases but utility decreases. Consequently, no matter whether the information is symmetrical or asymmetrical, collector 2, who has peer-induced fairness concerns, is at a disadvantage, which is consistent with the previous studies.



(a) (b)

Figure 3. The influence of the peer-induced fairness concerns coefficient on the collector 2's profits and performance. (**a**) The influence of the peer-induced fairness concerns coefficient on the collector 2's profits. (**b**) The influence of the peer-induced fairness concerns coefficient on the collector 2's performance.

7. Conclusions

Consider the fact that the collector concerns not only distributes fairness but also the fairness among peers. Based on the Nash bargain theory, a fairness concerns utility system is established for the CLSC with one manufacturer, one retailer, and two collectors so as to study the pricing decisions in the CLSC. Suppose that the manufacturer is the leader of the CLSC who first sets the wholesale price and the transfer price, and then the retailer and the collectors set the retailer price and collection price. Through backward induction, the equilibrium solutions of the collectors in the discrete and the centralized cases under neutral fairness can be obtained. Then, based on the Nash bargain fairness reference framework, the collectors' equilibrium solutions under fairness concerns can be obtained. The last part of the paper discusses a case where the manufacturer considers the collector's fairness concerns and examines how to design an incentive contract to improve his own profits.

The study suggests that whether fairness concerns information is symmetrical or asymmetrical, the equilibrium solution of CLSC models changes with fairness concerns, and that under conditions of symmetrical information, the manufacturer is forced to raise the transfer price, thus making the collector increase their collection prices to directly achieve reciprocity with the manufacturer. However, the retailer's fairness concerns improve his own interests but hurt the manufacturer's. Furthermore, the transfer price of collector 2, who is concerned with both distributional and peer-induced fairness, is lower than that of collector 1, who is only concerned with distributional fairness. Under asymmetrical information of fairness concerns, since the manufacturer does not consider the collector's fairness concerns, the collectors reduce their collection to indirectly "punish" the manufacturer. However, collector 2 will raise the collection price to make his profits no less than collector 1's. No matter whether the information is symmetrical or asymmetrical, to obtain a market proposition that is not less than that of collector 1, collector 2, who is concerned with peer-induced fairness, puts himself at a disadvantage.

We also find that the two types of fairness concerns have opposite impacts on all of the members' decisions in the CLSC. The distributional fairness concerns increase the profits of the collector at the cost of sacrificing the manufacturer's profits, and peer-induced fairness concerns benefit the manufacturer at the cost of sacrificing the collector's profits.

We also find that, under the asymmetric information of fairness concerns, collector 2 will increase the collection price and the collection quantity as the fairness concerns coefficient increases to ensure that his profit is not lower than that of collector 1.

We propose a two-part tariff contract where the manufacturer considers the collector's fairness concerns. The theoretical and numeral studies indicate that under the established contract the profits of both the manufacturer and the collectors achieve Pareto improvement.

In a deeper sense, this paper contributes to our understanding about the interaction between distributional and peer-induced fairness concerns, and the value of fairness concerns information to CLSC decisions.

However, the paper only considers the impact of fairness concerns on pricing decisions in a CLSC. Since several collectors are involved in collection activity in the same market, the influence of competitive intensity between collectors on pricing decisions in a CLSC deserves further study. In addition, in our paper, it is assumed that the function of collection quantity is linear, but the collection quantity of used products in reality is often affected by many factors. Therefore, considering the competition between collectors and the random function of collection quantity merit further research.

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Appendix A

Proof of Corollary 1. According to the equilibrium solutions in centralized and decentralized cases, the following expressions can be obtained:

$$\begin{gathered} p_o^* - p^* = \tfrac{-a+bc_m}{4b} < 0,\ D_o^* - D^* = \tfrac{a-bc_m}{4} > 0,\ A_{io}^* - A_i^* = \tfrac{\Delta - h_i}{4} > 0, \\ G_o^* - G^* = \tfrac{2\Delta+h}{4} > 0,\ \tfrac{(G_o^*-G^*)/G_o^*}{(D_o^*-D^*)/D_o^*} = 1,\ r_o^* - r^* = 0, \\ u_{sco}^* - u_{sc}^* = \tfrac{(a-bc_m)^2}{16b} + \tfrac{(\Delta+h_1)^2}{16} + \tfrac{(\Delta+h_2)^2}{16} > 0. \end{gathered} \tag{A1}$$

□

Proof of Corollary 2. According to the expressions of B_1^{SI-f*}, and B_2^{SI-f*}, we can get:

$$\frac{\partial B_1^{SI-f*}}{\partial \lambda_T} = \frac{\Delta + h_1}{(2+\lambda_T)^2} > 0,\ \frac{\partial B_2^{SI-f*}}{\partial \lambda_T} = \frac{(1+\theta)(\Delta+h_2)}{(2+2\theta+\lambda_T)^2} > 0,\ \frac{\partial B_2^{SI-f*}}{\partial \theta} = -\frac{\lambda_T(\Delta+h_2)}{(2+2\theta+\lambda_T)^2} < 0. \tag{A2}$$

□

Proof of Corollary 3. From the expressions of B_1^*, B_1^{SI-f*}, B_2^*, and B_2^{SI-f*}, we can get:

$$\begin{gathered} B_1^{SI-f*} - B_1^* = \tfrac{\lambda_T(\Delta+h_1)}{2(2+\lambda_T)} > 0,\ \tfrac{\partial(B_1^{SI-f*}-B_1^*)}{\partial \lambda_T} = \tfrac{\Delta+h_1}{(2+\lambda_T)^2} > 0, \\ B_2^{SI-f*} - B_2^* = \tfrac{\lambda_T(\Delta+h_2)}{2(2+2\theta+\lambda_T)} > 0,\ \tfrac{\partial(B_2^{SI-f*}-B_2^*)}{\partial \lambda_T} = \tfrac{(1+\theta)(\Delta+h_2)}{(2+2\theta+\lambda_T)^2} > 0. \end{gathered} \tag{A3}$$

□

Proof of Corollary 4. It can be known from the expressions of B_1^{SI-f*} and B_2^{SI-f*}, if $h_1 = h_2 = \frac{h}{2}$, then

$$B_2^{SI-f*} - B_1^{SI-f*} = \frac{-\theta\lambda_T(2\Delta+h)}{2(2+\lambda_T)(2+2\theta+\lambda_T)} < 0. \tag{A4}$$

□

Proof of Corollary 5. By replacing P^{SI-f*}, B_1^{SI-f*}, A_1^{SI-f*}, B_2^{SI-f*}, and A_2^{SI-f*} into the profit function of the manufacturer, it becomes:

$$\frac{\partial \pi_M^{SI-f*}}{\partial \lambda_T} < 0 \text{ and } \frac{\partial \pi_M^{SI-f*}}{\partial \theta} = \frac{\lambda_T(\Delta + h_2)^2}{4(2+2\theta+\lambda)^2} > 0. \tag{A5}$$

□

Proof of Corollary 6. By replacing B_1^{SI-f*}, A_1^{SI-f*}, B_2^{SI-f*}, and A_2^{SI-f*} into the profit function of the collectors, we can obtain:

$$\begin{gathered} \frac{\partial \pi_{T_1}^{SI-f*}}{\partial \lambda_T} = \frac{(\Delta+h_1)^2}{4(2+\lambda_T)^2} > 0,\ \frac{\partial \pi_{T_2}^{SI-f*}}{\partial \lambda_T} = \frac{(1+\theta)(\Delta+h_2)^2}{4(2+2\theta+\lambda_T)^2} > 0, \\ \frac{\partial \pi_{T_2}^{SI-f*}}{\partial \theta} = -\frac{\lambda_T(\Delta+h_2)^2}{4(2+2\theta+\lambda_T)^2} < 0. \end{gathered} \tag{A6}$$

□

Proof of Corollary 7. It can be obtained from the expressions of A_1^{AI-f*} and A_2^{AI-f*}, we can obtain:

$$\frac{\partial A_1^{AI-f*}}{\partial \lambda_T} = -\frac{\Delta + h_1}{8} < 0,\ \frac{\partial A_2^{AI-f*}}{\partial \lambda_T} = -\frac{\Delta + h_2}{8(1+\theta)} < 0,\ \frac{\partial A_2^{AI-f*}}{\partial \theta} = \frac{\lambda_T(\Delta + h_2)}{8(1+\theta)^2} > 0. \tag{A7}$$

□

Proof of Corollary 8. It can be known from the expressions of A_1^{AI-f*} and A_2^{AI-f*}, if $h_1 = h_2 = \frac{h}{2}$, then

$$A_2^{AI-f*} - A_1^{AI-f*} = \frac{\theta(2\Delta + h)}{16(1+\theta)} > 0. \tag{A8}$$

□

Proof of Corollary 9. By replacing p^{AI-f*} and A_i^{AI-f*} into the demand function and the expressions of collection quantity, we can obtain:

$$\frac{\partial r^{AI-f*}}{\partial \lambda_T} = -\frac{(2\Delta + h) + \theta(\Delta + h_1)}{2(1+\theta)(a - bc_m)} < 0,\ \frac{\partial r^{AI-f*}}{\partial \theta} = \frac{\lambda_T(\Delta + h_2)}{2(1+\theta)^2(a - bc_m)} > 0. \tag{A9}$$

□

Proof of Corollary 10. Replace P^{AI-f*}, B_1^{AI-f*}, A_1^{AI-f*}, B_2^{AI-f*}, and A_2^{AI-f*} into the profit function of the manufacturer, we get:

$$\frac{\partial \pi_M^{AI-f*}}{\partial \lambda_T} = -\frac{(\Delta + h_1)^2}{16} - \frac{(\Delta + h_2)^2}{16(1+\theta)} < 0,\ \frac{\partial \pi_M^{AI-f*}}{\partial \theta} = \frac{\lambda_T(\Delta + h_2)^2}{16(1+\theta)^2} > 0. \tag{A10}$$

□

Proof of Corollary 11. Replace B_1^{AI-f*}, A_1^{AI-f*}, B_2^{AI-f*}, and A_2^{AI-f*} into the profit function of the collectors, we get:

$$\frac{\partial \pi_{T_i}^{AI-f*}}{\partial \lambda_T} = -\frac{\lambda_T(\Delta + h_i)^2}{32} < 0,\ \frac{\partial \pi_{T_2}^{AI-f*}}{\partial \theta} = \frac{\lambda_T^2(\Delta + h_2)^2}{32(1+\theta)^2} > 0. \tag{A11}$$

□

Proof of Corollary 12. Due to the expressions of A_i^{SI-f*} and A_i^{AI-f*}, it becomes:

$$\begin{gathered}A_1^{SI-f*} - A_1^{AI-f*} = \frac{\lambda_T(\Delta+h_1)}{8} > 0,\ A_2^{SI-f*} - A_2^{AI-f*} = \frac{\lambda_T(\Delta+h_2)}{8(1+\theta)} > 0,\\ \frac{\partial(A_1^{SI-f*}-A_1^{AI-f*})}{\partial\lambda_T} = \frac{\Delta+h_1}{8} > 0,\ \frac{\partial(A_2^{SI-f*}-A_2^{AI-f*})}{\partial\lambda_T} = \frac{\Delta+h_2}{8(1+\theta)} > 0,\\ \frac{\partial(A_2^{SI-f*}-A_2^{AI-f*})}{\partial\theta} = -\frac{\lambda_T(\Delta+h_2)}{8(1+\theta)^2} < 0.\end{gathered} \tag{A12}$$

□

Proof of Corollary 13. By replacing p^{SI-f*}, p^{AI-f*}, A_i^{SI-f*}, and A_i^{AI-f*} into the demand function and the expressions of collection quantity, it becomes:

$$\begin{gathered}r^{SI-f*} - r^{AI-f*} = \frac{\lambda_T(2\Delta+h)+\lambda_T\theta(\Delta+h_1)}{2(1+\theta)(a-bc_m)} > 0,\ \frac{\partial(r^{SI-f*}-r^{AI-f*})}{\partial\lambda_T} = \frac{(2\Delta+h)+\theta(\Delta+h_1)}{2(1+\theta)(a-bc_m)} > 0,\\ \frac{\partial(r^{SI-f*}-r^{AI-f*})}{\partial\theta} = -\frac{\lambda_T(\Delta+h_2)}{2(1+\theta)^2(a-bc_m)} < 0.\end{gathered} \tag{A13}$$

□

Proof of Corollary 14.

$$\begin{gathered}r^{t*} - r^{SI-f*} = \frac{2\Delta+h}{a-bc_m} > 0,\ \pi_M^{t*} - \pi_M^{SI-f*} = \frac{(1+\theta)(2+\lambda_T)(\Delta+h_2)^2+2(1+\theta)(\Delta+h_1)^2}{8(2+\lambda_T)(2+2\theta+\lambda_T)} > 0,\\ \pi_{T_1}^{t*} - \pi_{T_1}^{SI-f*} = \frac{\lambda_T(\Delta+h_1)^2}{16(2+\lambda_T)} > 0,\ \pi_{T_2}^{t*} - \pi_{T_2}^{SI-f*} = \frac{\lambda_T(2+\lambda_T)(\Delta+h_2)^2+2\lambda_T\theta(\Delta+h_1)^2}{16(2+\lambda_T)(2+2\theta+\lambda_T)} > 0.\end{gathered} \tag{A14}$$

□

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