Journal of Mathematics and Informatics
Vol. 14, 2018, 69-78
ISSN: 2349-0632 (P), 2349-0640 (online)
Published 30 November 2018
www.researchmathsci.org
DOI: http://dx.doi.org/10.22457/jmi.v14a9

Journal of Mathematics and Informatics

Impact of Retailer's Bidirectional Fairness Concern on Closed-loop Supply Chain

***Xiao-ping Liu*[1] and *Qing Wang*[2]**

School of Economics and Management
Chongqing University of Posts and Telecommunications
Chongqing – 400065, Chongqing,
[1]Corresponding author. E-mail: liuxiaoping@cqupt.edu.cn

Received 1 November 2018; accepted 29 November 2018

Abstract. Build a closed-loop supply chain which consists of the manufacturer, the remanufacturer and the retailer, taking the patent protection factor as the basic variable of the closed-loop supply chain decision-making model, introducing the retailer's bidirectional fairness concerns factor. The influence of the manufacturer and the remanufacturer considering or not considering the retailer's fairness concerns to the demand of products and the profit of the closed-loop supply chain is researched by using game theory. The results show that: the retailer's bidirectional fairness concerns does not affect the demand of products and the profit of system when the manufacturer and the remanufacturer consider the retailer's fairness concerns. The retailer's bidirectional fairness concern will reduce the demand of products and the profit of system when the manufacturer and the remanufacturer do not consider the retailer's fairness concerns. where, the retailer's fairness concerns about the manufacturer impact on the demand of products and the profit of system is higher than its fairness concerns about the remanufacturer.

Keywords: Closed-loop supply chain; bidirectional fairness concerns; patent licensing

AMS Mathematics Subject Classification (2010): 90B05

1. Introduction

As an important part of the economic cycle development, the remanufacturing industry has the unique advantages of cost saving, energy saving, material saving and emission reduction, which has attracted great attention from the business community and academia. Companies typically have two models for remanufacturing activities: one is a remanufacturing activity by an original equipment manufacturer; and the other is a remanufacturing activity by a third-party remanufacturer. Research shows that remanufacturing by the remanufacturer is more conducive to increasing consumers' perceived value of new products compared to the manufacturer remanufacturing[1]. Therefore, more and more original equipment manufacturers are beginning to outsource remanufacturing activities to remanufacturers. However, the sales of remanufactured products will invaded the market share of new products to a certain extent. In order to maintain the market share of new products and gain more profits, OEMs began to delegate remanufacturing activities to remanufacturers in the form of patent licenses(such as Apple). The introduction of remanufacturers has changed the original profit distribution pattern of the closed-loop supply chain. Research by behavioral economist Kehnema et al. shows that people tend to show great attention to the distribution of profits, which leads to fairness concerns[2]. Therefore, when manufacturers introduce remanufacturers into the closed-loop supply chain through patent licensing, it is important to study the impact of fairness concerns on the closed-loop supply chain.

The decision-making research on the closed-loop supply chain under patent protection has achieved fruitful results. Zhong-kai et al. studied the product pricing strategy under the patent protection, and realized the coordination of the closed-loop supply chain by using the revenue-cost sharing mechanism[3]. Cheng-ran et al. have further promoted Zhong-kai's research [4]. Jian-ming et al. studied the impact of patent protection on closed-loop supply chain pricing strategies under differential pricing [5]. Ben-rong et al. introduced patent protection in the research of closed-loop supply chain channel strategy, which further enriched the research in this field [6].

All above literatures assume that the decision makers in the closed-loop supply chain are completely rational, but the behavioral economics research shows that the decision makers are often not completely rational, especially sensitive to the unfairness of the distribution of benefits. Ho et al. first used empirical research to show that there is fairness concerns in the supply chain [7]. Then, the scholars' research on the behavior of fairness concerns in the supply chain is mainly divided into: channel coordination under fairness concerns [8-9], supply chain coordination [10], etc. Ke-yong et al. first introduced the behavior of fairness concerns into the closed-loop supply chain and studied the impact of fairness concerns on product pricing strategies [11]. Subsequently, the scholars studied the pricing and coordination strategies of the closed-loop supply chain based on the manufacturer's fairness concerns [12-14], the remanufacturer's fairness concerns[15] and the retailer's fairness concerns [16-17], where, Zhang-yue et al. scholars studied the impact of the manufacturer's bidirectional fairness concerns on the bargaining power of the decision makers of the closed-loop supply chain, but ignored the possibility of patent protection in closed-loop supply chain.

In summary, firstly, the research on the impact of patent protection on the closed-loop supply chain has achieved fruitful research results. However, in the context of patent protection in the closed-loop supply chain, further discussion on the impact of other factors (such as: fairness concerns) on the closed-loop supply chain remains to be further explored. Secondly, when the system is constructed from three subjects, a single subject tends to have fairness concerns at the same time for the other two subjects. The existing research mainly discusses the impact of one-way fairness concerns on the closed-loop supply chain, but the research on the bidirectional fairness concerns in the closed-loop supply chain is not deep enough. Therefore, there is an urgent need to expand the object of fairness concerns from one-way to bidirectional for further research.

Different from previous researches, this paper constructs a closed-loop supply chain consists of the manufacturer, the remanufacturer and the retailer, and takes patent protection factors as the basic variables of the closed-loop supply chain decision-making model. To focus on: under the bidirectional fairness concerns of the retailer, the effect and extent of the impact of each one-way fairness concerns(including the retailer’s fairness concerns to the manufacturer and the retailer’s fairness concerns to the remanufacturer) on the demand of products and profits of the closed-loop supply chain. To assist the supply chain to control and manage each one-way fairness concerns, and minimize the adverse impact of the retailer's bidirectional fairness concerns on the closed-loop supply chain.

2. Problem description and assumption

Research in a closed-loop supply chain consists of the manufacturer, the remanufacturer, and the retailer, when the manufacturer patent licensing to the remanufacturer, to study the impact of the retailer's bidirectional fairness concerns on the demand of products and the profit of closed-loop supply chain. The stackelberg game with the manufacturer as the leader in the closed-loop supply chain system. The manufacturer and the remanufacturer are unfairness concerns, where the manufacturer is responsible for the production of new products, and the remanufacturer is responsible for recycling and producing remanufactured products, the retailer has bidirectional fairness concerns and is responsible for selling new and remanufactured products. Figure 1 shows the closed-loop supply chain decision structure model.

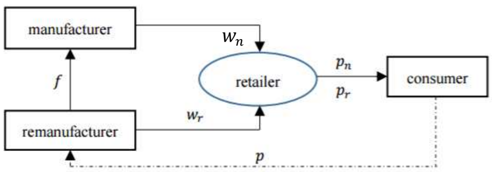

Figure 1: Closed-loop supply chain decision structure

Based on the above basic description, the following describes the symbols and basic assumptions of this article.

(1) The recycled old products can all be used for remanufacturing, and the output of new products and remanufactured products can exactly meet the needs of the market.

(2) The unit cost, wholesale price, and sales price of the products are: c_i, w_i, p_i, where $i = (n, r)$ denotes the new product and the remanufactured product respectively. To ensure that all members of the closed-loop supply chain system are profitable, they must be satisfied: $p_n > w_n > c_n$, $p_r > w_r > c_r$.

(3) The unit patent fee is f; the unit cost of recycling old products is p.

(4) Assume that consumers have heterogeneous demands for new products and remanufactured products: Consumers' willingness to pay for new products is $V \sim N[0,1]$. Compared to new products, consumers' willingness to pay for remanufactured products is $\theta \in [0,1]$. Assume that the market's total demand is $Q = 1$, in order to enable consumers to have the desire to purchase remanufactured products, this article only analyzes the situation of $\theta p_n > p_r$. According to the utility function derivation: $q_n = 1 - \frac{p_n - p_r}{1-\theta}$, $q_r = \frac{\theta p_n - p_r}{\theta(1-\theta)}$, where q_n represents the market demand for new products, q_r represents the market demand for remanufactured products.

(5) Π_j^k represents the profit of system member j in model k, where $j = (N, R, r)$ represents the manufacturer, the remanufacturer, and the retailer respectively. And $k = (I, D, F, NF)$ represents the centralized decision-making model, the decentralized decision-making model, the decentralized decision model under the manufacturer and the remanufacturer consider the retailer's fairness concerns and the decentralized decision

model under the manufacturer and the remanufacturer not consider the retailer's fairness concerns. All the profits in this article are the theoretical profits when the product sales exactly meet the demand of products.

(6) ζ_1 indicates the retailer's fairness concerns factor for the manufacturer, and ζ_2 indicates the retailer's fairness concerns for the remanufacturer.

(7) To make the study meaningful, we assume $(1-c_n)(1-\theta) > \theta c_n - c_r - p$.

3. The decision of closed-loop supply chain under unfairness concerns

3.1. The centralized decision model

Under the centralized decision model, the manufacturer, the remanufacturer and the retailer build a decision-making system to determine pricing strategies for new products and remanufactured products to maximize system's profits. The profits of the system is:

$$\Pi_c{}^I = (p_n - c_n)q_n + (p_r - c_r - p)q_r \quad (1)$$

To solution $\frac{\partial \Pi_c{}^I}{\partial p_n} = 0$, $\frac{\partial \Pi_c{}^I}{\partial p_r} = 0$ simultaneously: $p_n{}^I = \frac{1+c_n}{2}, p_r{}^I = \frac{\theta+c_r+p}{2}$;

Therefore, the demand for new and remanufactured products and the profits of system are:

$$q_n{}^I = \frac{1-\theta-c_n+c_r+p}{2(1-\theta)}, q_r{}^I = \frac{\theta c_n - c_r - p}{2\theta(1-\theta)};\ \Pi_c{}^I = \frac{(1-c_n)^2}{4} + \frac{(\theta c_n - c_r - p)^2}{4\theta(1-\theta)};$$

3.2. The decentralized decision model

Under the decentralized decision model, relevant decisions of each members of the system are based on maximizing their own profits.

The profit function for the manufacturer, the remanufacturer and the retailer are:

$$\Pi_M = (w_n - c_n)q_n + f q_r \quad (2)$$

$$\Pi_R = (w_r - c_r - p - f)q_r \quad (3)$$

$$\Pi_r = (p_n - w_n)q_n + (p_r - w_r)q_r \quad (4)$$

In a stackelberg game with the manufacturer as the leader, solving the above profit function inversely according to the game sequence can be obtained:

$$p_n{}^D = \frac{3+c_n}{4},\ p_r{}^D = \frac{6\theta+\theta c_n+c_r+p}{8};\ w_r{}^D = \frac{\theta c_n+c_r+p+2\theta}{4},\ w_n{}^D = \frac{1+c_n}{2};\ f^D = \frac{\theta-c_r-p}{2};$$

Therefore, the demand of new and remanufactured products are:

$$q_n{}^D = \frac{2(1-\theta-c_n)+\theta c_n+c_r+p}{8(1-\theta)}, q_r{}^D = \frac{\theta c_n - c_r - p}{8\theta(1-\theta)};$$

The profits of the manufacturer, the remanufacturer and the retailer are:

$$\Pi_M{}^D = \frac{2\theta-2\theta^2-4\theta c_n+4\theta^2 c_n+2\theta c_n{}^2-\theta^2 c_n{}^2-2\theta c_n(c_r+p)+(c_r+p)^2}{16\theta(1-\theta)};$$

$$\Pi_R{}^D = \frac{(\theta c_n - c_r - p)^2}{32\theta(1-\theta)};$$

$$\Pi_r{}^D = \frac{4\theta-4\theta^2-8\theta c_n+8\theta^2 c_n+4\theta c_n{}^2-3\theta^2 c_n{}^2-2\theta c_n(c_r+p)+(c_r+p)^2}{64\theta(1-\theta)};$$

4. The decision of closed-loop supply chain under the retailer's bidirectional fairness concerns

This article assumes that in the closed-loop supply chain system, the manufacturer and the remanufacturer are unfairness concerns, the retailer have bidirectional fairness concerns, where the retailer has fairness concerns for the manufacturer(call it below: vertical one fairness concerns) and fairness concerns for the remanufacturer(call it below: vertical two fairness concerns). In this paper, we refer to the studies of Shao-fu[18] and Zhang-yue[14], assuming that the retailer's fairness concerns utility function is:

$$U_r = \Pi_r - \zeta_1(\Pi_M - \Pi_r) - \zeta_2(\Pi_R - \Pi_r) \quad (5)$$

The retailer's fairness concerns utility function is divided into three parts: the first part is the retailer's profit function, the second part is the retailer's fairness concerns utility function for the manufacturer, and the third part is the retailer's fairness concerns utility function for the remanufacturer, where $\zeta_i \in [0,1]$ (i =1,2) indicates the retailer's degree of fairness concerns, and the more ζ_i tends to 0, the lower the fairness concerns of the retailer, the more it tends to 1, the higher the fairness concerns of the retailer[17].

4.1 The manufacturer and the remanufacturer consider the retailer's fairness concerns

When the manufacturer and the remanufacturer consider the retailer's fairness concerns, the retailer's fairness concerns will directly influence the manufacturer's and the remanufacturer's pricing decisions. At this point, the retailer's strategy is based on the maximization of the utility function, and the strategy of the manufacturer and the remanufacturer are based on maximizing the profit function. The same as the game order under the decentralized decision, using the inverse solution method:

$$p_n{}^F = \frac{3+c_n}{4}; p_r{}^F = \frac{\theta c_n + cr + p}{8} + \frac{3\theta}{4}; f^F = \frac{(\theta - c_r - p)(1+\zeta_1+\zeta_2)}{2+4\zeta_1+2\zeta_2} = F;$$

$$w_n{}^F = \frac{1+\zeta_1+\zeta_2+c_n(1+3\zeta_1+\zeta_2)}{2+4\zeta_1+2\zeta_2} = E; w_r{}^F = \frac{\theta(1+2\zeta_1+\zeta_2)}{2+2\zeta_1+4\zeta_2}E + \frac{1+3\zeta_2}{2+2\zeta_1+4\zeta_2}F + G;$$

where $\mathrm{G} = \frac{(c_r+p)(1+\zeta_1+3\zeta_2) - \theta c_n \zeta_1}{2+2\zeta_1+4\zeta_2}$, the demand of products are:

$$q_n{}^F = \frac{\theta c_n - 2c_n + c_r + p - 2\theta + 2}{8(1-\theta)};\ q_r{}^F = \frac{\theta c_n - cr - p}{8\theta(1-\theta)};$$

Bringing product pricing and demand into the profit function can earn the profits of each member and system, omitted here.

Proposition 1. When the manufacturer and the remanufacturer consider the retailer's fairness concerns: $p_n{}^F = p_n{}^D$, $p_r{}^F = p_r{}^D$; $q_n{}^F = q_n{}^D$, $q_r{}^F = q_r{}^D$.
Proof: omission.

Proposition 1 indicates that: When the manufacturer and the remanufacturer consider the retailer's fairness concerns, product pricing and demand are not affected by the retailer's fairness concerns. Therefore, the retailer's fairness concerns will only affect the profit distribution among the members and will not affect the profits of the system.

Proposition 2. When the manufacturer and the remanufacturer consider the retailer's fairness concerns:

(1) $\frac{\partial \Pi_M{}^F}{\partial \xi_1} < 0, \frac{\partial \Pi_M{}^F}{\partial \xi_2} > 0; \left|\frac{\partial \Pi_M{}^F}{\partial \xi_1}\right| > \left|\frac{\partial \Pi_M{}^F}{\partial \xi_2}\right|;$

(2) $\frac{\partial \Pi_R{}^F}{\partial \xi_1} > 0, \frac{\partial \Pi_R{}^F}{\partial \xi_2} < 0; \left|\frac{\partial \Pi_R{}^F}{\partial \xi_1}\right| < \left|\frac{\partial \Pi_R{}^F}{\partial \xi_2}\right|;$

(3) $\frac{\partial \Pi_r{}^F}{\partial \xi_1} > 0, \frac{\partial \Pi_r{}^F}{\partial \xi_2} < 0; \left|\frac{\partial \Pi_r{}^F}{\partial \xi_1}\right| > \left|\frac{\partial \Pi_r{}^F}{\partial \xi_2}\right|;$

(4) $\frac{\partial \Pi_c{}^F}{\partial \xi_1} = 0, \frac{\partial \Pi_c{}^F}{\partial \xi_2} = 0$

Proof: Find the partial derivative of the profit of each members and system with respect to the factor of fairness concerns $\xi_1$and ξ_2 respectively. Take manufacturer as an example.

$$\frac{\partial \Pi_M{}^F}{\partial \zeta_1} = \frac{\partial w_n{}^F}{\partial \zeta_1} q_n{}^F + \frac{\partial f^F}{\partial \zeta_1} q_r{}^F; \frac{\partial \Pi_M{}^F}{\partial \zeta_2} = \frac{\partial w_n{}^F}{\partial \zeta_2} q_n{}^F + \frac{\partial f^F}{\partial \zeta_2} q_r{}^F;$$

Because: $\frac{\partial w_n{}^F}{\partial \zeta_1} = \frac{2(1+\zeta_2)(c_n-1)}{(2+4\zeta_1+2\zeta_2)^2} < 0, \frac{\partial w_n{}^F}{\partial \zeta_2} = \frac{2\zeta_1(1-c_n)}{(2+4\zeta_1+2\zeta_2)^2} > 0, \left|\frac{\partial w_n{}^F}{\partial \zeta_1}\right| > \left|\frac{\partial w_n{}^F}{\partial \zeta_2}\right|$,

based on proposition 1, obviously: $\frac{\partial \Pi_M{}^F}{\partial \zeta_1} < 0, \frac{\partial \Pi_M{}^F}{\partial \zeta_2} > 0; \left|\frac{\partial \Pi_M{}^F}{\partial \xi_1}\right| > \left|\frac{\partial \Pi_M{}^F}{\partial \xi_2}\right|$.

The certification of other members and system is the same as manufacturer. The proposition 2 is proofed.

Proposition 2 indicates that: When the manufacturer and the remanufacturer consider the retailer's fairness concerns, the manufacturer's profits decrease with vertical one fairness concerns and increase with vertical two fairness concerns, vertical one fairness concerns has a higher impact on the profits of the manufacturer than vertical two fairness concerns, therefore, the retailer's bidirectional fairness concerns reduces the manufacturer's profits. The remanufacturer's profits increase with vertical one fairness concerns and decrease with vertical two fairness concerns, vertical two fairness concerns has a higher impact on the profits of the remanufacturer than vertical one fairness concerns, therefore, the retailer's bidirectional fairness concerns reduces the remanufacturer's profits. The retailer's profits increase with vertical one fairness concerns and decrease with vertical two fairness concerns, vertical one fairness concerns has a higher impact on the profits of the retailer than vertical two fairness concerns, therefore, the retailer's bidirectional fairness concerns increases the retailer's profits.

4.2. The manufacturer and the remanufacturer not consider the retailer's fairness concerns

Due to the lack of information circulation in the closed-supply chain, or the manufacturer and the remanufacturer completely dominate the market, will cause the manufacturer and the remanufacturer to disregard the retailer's fairness concerns[15]. Therefore, it is necessary to make a specific analysis of the decision of the closed-loop supply chain under this situation.

When the manufacturer and the remanufacturer not consider the retailer's fairness concerns, the manufacturer and the remanufacturer make decision based on non-fairness concerns in the system. Their pricing decision are the same as the pricing decision under unfairness concerns decentralized decision, where:

$$w_n{}^N = w_n{}^D = \frac{1+c_n}{2}, w_r{}^N = w_r{}^D = \frac{\theta c_n + c_r + p + 2\theta}{4},\ f^N = f^D = \frac{\theta - c_r - p}{2}.$$

But the retailer's decision is also based on maximizing its fairness utility function. Then:

$$p_n{}^N = \frac{c_n(1+\zeta_2)+3+4\zeta_1+3\zeta_2}{4(1+\zeta_1+\zeta_2)}; p_r{}^N = \frac{\theta c_n(1+\zeta_1+2\zeta_2)+(c_r+p)(1-\zeta_1)+\theta(6+8\zeta_1+6\zeta_2)}{8(1+\zeta_1+\zeta_2)};$$

$$q_n{}^N = \frac{\theta c_n(1+\zeta_1+2\zeta_2)+(c_r+p)(1-\zeta_1)-2(1+\zeta_2)(c_n+\theta-1)}{8(1-\theta)(1+\zeta_1+\zeta_2)}; q_r{}^N = \frac{(\theta c_n - c_r - p)(1-\zeta_1)}{8\theta(1-\theta)(1+\zeta_1+\zeta_2)};$$

Bringing product pricing and demand into the profit function can earn the profits of each members and system, omitted here.

Proposition 3. When the manufacturer and the remanufacturer not consider the retailer's fairness concerns:

(1) $\frac{\partial q_n{}^N}{\partial \zeta_1} < 0, \frac{\partial q_n{}^N}{\partial \zeta_2} > 0; \left|\frac{\partial q_n{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial q_n{}^N}{\partial \zeta_2}\right|$; (2) $\frac{\partial q_r{}^N}{\partial \zeta_1} < 0, \frac{\partial q_r{}^N}{\partial \zeta_2} < 0; \left|\frac{\partial q_r{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial q_r{}^N}{\partial \zeta_2}\right|$;

Proof: Find the partial derivative of the demand of products with respect to the factor of fairness concerns $\xi_1$and ξ_2 respectively.

$$\frac{\partial q_n{}^N}{\partial \zeta_1} = -\frac{(\theta c_n - c_r - p)\zeta_2 + (1 + c_r + p - \theta - c_n)(2 + 2\zeta_2)}{8(1-\theta)(1+\zeta_1+\zeta_2)^2};$$

$$\frac{\partial q_n{}^N}{\partial \zeta_2} = \frac{[(\theta c_n - c_r - p) + 2(1 + c_r + p - \theta - c_n)]\zeta_1 + \theta c_n - c_r - p}{8(1-\theta)(1+\zeta_1+\zeta_2)^2};$$

Because: $(1 - c_n)(1 - \theta) > \theta c_n - c_r - p$, obviously,

$$\frac{\partial q_n{}^N}{\partial \zeta_1} < 0, \frac{\partial q_n{}^N}{\partial \zeta_2} > 0; \left|\frac{\partial q_n{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial q_n{}^N}{\partial \zeta_2}\right|$$

$$\frac{\partial q_r{}^N}{\partial \zeta_1} = -\frac{(\theta c_n - c_r - p)(2+\zeta_2)}{8\theta(1-\theta)(1+\zeta_1+\zeta_2)^2}; \quad \frac{\partial q_r{}^N}{\partial \zeta_2} = -\frac{(\theta c_n - c_r - p)(1-\zeta_1)}{8\theta(1-\theta)1+\zeta_1+\zeta_2)^2};$$

Obviously: $\frac{\partial q_r{}^N}{\partial \zeta_1} < 0, \frac{\partial q_r{}^N}{\partial \zeta_2} < 0; \left|\frac{\partial q_r{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial q_r{}^N}{\partial \zeta_2}\right|$. Proposition 3 is proved.

Proposition 3 indicates that: When the manufacturer and the remanufacturer not consider the retailer’s fairness concerns, the demand of new products decrease with vertical one fairness concerns and increase with vertical two fairness concerns, vertical one fairness concerns has a higher impact on the demand of new products than vertical two fairness concerns, therefore, the retailer’s bidirectional fairness concerns reduces the demand of new products. The demand of remanufactured products decrease with vertical one and vertical two fairness concerns, vertical one fairness concerns has a higher impact on the demand of remanufactured products than vertical two fairness concerns, therefore, the retailer’s bidirectional fairness concerns reduces the demand of remanufactured products.

Proposition 4. When the manufacturer and the remanufacturer not consider the retailer’s fairness:

(1) $\frac{\partial \Pi_M{}^N}{\partial \zeta_1} < 0, \lim_{\zeta_1 \to 0} \frac{\partial \Pi_M{}^N}{\partial \zeta_2} < 0, \lim_{\zeta_1 \to 1} \frac{\partial \Pi_M{}^N}{\partial \zeta_2} > 0; \left|\frac{\partial \Pi_M{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial \Pi_M{}^N}{\partial \zeta_2}\right|$;

(2) $\frac{\partial \Pi_R{}^N}{\partial \zeta_1} < 0, \frac{\partial \Pi_R{}^N}{\partial \zeta_2} < 0; \left|\frac{\partial \Pi_R{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial \Pi_R{}^N}{\partial \zeta_2}\right|$;

(3) $\frac{\partial \Pi_r{}^N}{\partial \zeta_1} < 0, \lim_{\zeta_1 \to 0} \frac{\partial \Pi_r{}^N}{\partial \zeta_2} < 0, \lim_{\zeta_1 \to 1} \frac{\partial \Pi_r{}^N}{\partial \zeta_2} > 0; \left|\frac{\partial \Pi_r{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial \Pi_r{}^N}{\partial \zeta_2}\right|$;

(4) $\frac{\partial \Pi_c{}^N}{\partial \zeta_1} < 0, \lim_{\zeta_1 \to 0} \frac{\partial \Pi_c{}^N}{\partial \zeta_2} < 0, \lim_{\zeta_1 \to 1} \frac{\partial \Pi_c{}^N}{\partial \zeta_2} > 0; \left|\frac{\partial \Pi_c{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial \Pi_c{}^N}{\partial \zeta_2}\right|$;

Proof: Find the partial derivative of the profit of each members and system with respect to the factor of fairness concerns ξ_1 and ξ_2 respectively. Take the manufacturer as an example.

$$\frac{\partial \Pi_M{}^N}{\partial \zeta_1} = (w_n - c_n)\frac{\partial q_n{}^N}{\partial \zeta_1} + f\frac{\partial q_r{}^N}{\partial \zeta_1}; \quad \frac{\partial \Pi_M{}^N}{\partial \zeta_2} = \frac{\theta(1-c_n)M - (\theta - c_r - p)N}{16\theta(1-\theta)(1+\zeta_1+\zeta_2)^2};$$

where: $M = (\theta c_n - c_r - p)(1 + \zeta_1) + 2\zeta_1(1 + c_r + p - \theta - c_n), N = (\theta c_n - c_r - p)(1 - \zeta_1)$, based on proposition 3, obviously,

$$\frac{\partial \Pi_M{}^N}{\partial \zeta_1} < 0, \lim_{\zeta_1 \to 0} \frac{\partial \Pi_M{}^N}{\partial \zeta_2} < 0, \lim_{\zeta_1 \to 1} \frac{\partial \Pi_M{}^N}{\partial \zeta_2} > 0; \left|\frac{\partial \Pi_M{}^N}{\partial \zeta_1}\right| > \left|\frac{\partial \Pi_M{}^N}{\partial \zeta_2}\right|.$$

The certification of other members and system is the same as the manufacturer. The proposition 4 is proofed.

Proposition 4 indicates that: When the manufacturer and the remanufacturer not consider the retailer’s fairness concerns, the remanufacturer’s profits decrease with vertical one and vertical two fairness concerns. The manufacturer’s, the retailer’s and the system’s profits decrease with vertical one fairness concerns; the effect of the vertical two fairness concerns on the manufacturer's, the retailer's and the system's profits is affected by vertical one fairness concerns: When the degree of vertical one fairness concerns is towards 0, the manufacturer's, the retailer's and the system's profits decrease with vertical two fairness concerns, on the contrary, the manufacturer's, the retailer's and the system's profits increase with vertical two fairness concerns. Vertical one fairness concerns has a higher impact on the profits of each members and system than vertical two fairness concerns. The retailer's bidirectional fairness concerns reduces the profits of each members and system.

4.3. Comparative analysis

Proposition 5. Comparing the profits of each members and system in three situations, including: unfairness concerns, the manufacturer and the remanufacturer consider the retailer's fairness concerns, the manufacturer and the remanufacturer not consider the retailer's fairness concerns.

(1) ${\Pi_M}^D > {\Pi_M}^F > {\Pi_M}^N$;
(2) ${\Pi_R}^D > {\Pi_R}^F > {\Pi_R}^N$;
(3) ${\Pi_r}^F > {\Pi_r}^D > {\Pi_r}^N$;
(4) ${\Pi_c}^D = {\Pi_c}^F > {\Pi_c}^N$;

Proof: take the manufacturer as an example.

$${\Pi_M}^D - {\Pi_M}^F = \frac{(\theta c_n - c_r - p)^2 + 2\theta(1-\theta)(1-c_n)^2}{16\theta(1-\theta)(1+2\zeta_1+\zeta_2)};$$

$${\Pi_M}^F - {\Pi_M}^N = \frac{(\theta c_n - c_r - p)^2(3{\zeta_1}^2 + 3\zeta_1\zeta_2 + {\zeta_2}^2 + \zeta_1 + \zeta_2) + 2{\zeta_1}^2\theta(1-\theta)(1-c_n)^2}{16\theta(1-\theta)(1+2\zeta_1+\zeta_2)(1+\zeta_1+\zeta_2)};$$

Obviously, ${\Pi_M}^D - {\Pi_M}^F > 0, {\Pi_M}^F - {\Pi_M}^N > 0$. The certification of other members and system is the same as manufacturer. The proposition 5 is proofed.

Proposition 4 indicates that: When the manufacturer and the remanufacturer consider the retailer's fairness concerns, the profits of each members and system are greater than the profits when the retailer's fairness concerns is not considered. Compared with the profits under unfairness concerns, the retailer's fairness concerns reduces the profits of the manufacturer and the remanufacturer, increases its own profits, and keeps the total profit of the system unchanged.

6. Conclusion

This paper builds a closed-loop supply chain consists of the manufacturer, the remanufacturer and the retailer, background in which the manufacturer patent licensing the remanufacturing activity to the remanufacturer, to study the impact of the retailer's bidirectional fairness concerns on closed-loop supply chains. Get the following conclusion.

(1)When the manufacturer and the remanufacturer consider the retailer's fairness concerns, the demand of new and remanufactured products are not affected by the retailer's fairness concerns. When the manufacturer and the remanufacturer not consider the retailer's fairness concerns, the retailer's bidirectional fairness concerns reduces the demand of new and remanufactured products, where, vertical one fairness concerns has a higher impact on the demand of new and remanufactured products than vertical two fairness concerns.

(2)When the manufacturer and the remanufacturer consider the retailer's fairness concerns, the retailer's bidirectional fairness concerns increases its own profit but decreases the profit of the manufacturer and the remanufacturer, where, vertical one fairness concerns has a greater impact on the profit of the manufacturer and the retailer than vertical two fairness concerns, vertical two fairness concerns has a greater impact on the profit of the remanufacturer than vertical one fairness concerns. When the manufacturer and the remanufacturer not consider the retailer’s fairness concerns, the retailer’s bidirectional fairness concerns decreases the profit of each members and system, where, vertical one fairness concerns has a greater impact on the profit of each members and system than vertical two fairness concerns.

Through the above conclusions, we can get the following related management lessons:

The retailer’s fairness concerns from the manufacturer has a much greater impact on the demand of products(especially the demand of remanufactured products) and the profit of system than its fairness concerns from the remanufacturer. Therefore, focusing on managing the retailer's fairness concerns from the manufacturer can effectively reduce the losses to closed-loop supply chains caused by fairness concerns.

The research in this paper is based on the single-cycle closed-loop supply chain model, and the conclusions obtained are limited. Further research can extend the period of the model to multiple cycles, so that the conclusions of the study can be better applied to the actual situation.

REFERENCE

1. V.V. Agrawal, AAtasu and K.Van Ittersum, Remanufacturing, third-party competition, and consumer’s perceived value of new products, *Management Science*, 61(1) (2015) 60-72.
2. D.Kahneman, J.L.Knetsch and R.Thaler, Fairness competiton on profits seeking: Entitlements in the market, *American Economics Review*, 76(4) (1986) 728-741.
3. Zhong-kai Xiong, Chen-ran Shen, Zhi-qiang Peng, A remanufacturing strategy for the closed-loop supply chain under patent protection, *Journal of Industrial Engineering and Engineering Management*, 26(3) (2012) 159-165.
4. Chen-ran Shen, Zhong-kai Xiong and Zhi-qiang Peng. Decision and coordination research for remanufacturing closed-loop supply chain under patent protection and government subsidies, *Journal of Industrial Engineering and Engineering Management*, 27(3) (2013)132-138.
5. Jian-ming Wang, Differential price coordination contract of closed-loop supply chain with remanufacturing under patent protection, *Operations Research and Management Science*, 22(3) (2013) 89-96.
6. Ben-rong Zheng, Yang Chao and Yang Jun, Pricing and coordination strategy of dual-channel closed-loop supply chain under patent protection, *Journal of Systems Engineering*, 32(1) (2017) 103-113.
7. T.Ho and J.Zhang, Designing pricing contracts for boundedly rational customers: does the framing of the fixed fee matter? *Management Science*, 54(4) (2008) 686-700.
8. T.H.Cui, J.S.Raju and Z.J.Zhang, Fairness and channel coordination, *Management Science*, 53(8) (2007) 1303-1314.
9. C.D.Ozgun, Y.F.Chen and J.B.Li, Channel coordination under fairness concerns and nonlinear demand, *European Journal of Operational Research*, 207 (2010) 1321-1326.
10. Valery Pavolov and Elena Katok, *Fairness and supply chain coordination failures,*

Social Science Electronic Publishing, 2015.

11. Ke-yong Zhang, Shi-wang Hou and Guo-hua Zhou, Pricing strategy in the closed-loop supply chain with fairness concerns, *Journal of Systems & Management*, 22(6) (2013) 841-849.
12. Xue-feng Ding and Fang-fang Wei, Pricing decisions for manufacturer-driven closed-loop supply chain with fairness concerns, *Industrial Engineering Journal*, 17(4) (2014) 78-84.
13. Peng Gao and Jia-jia Nie, The strategy of patent authorization of closed-loop supply chain under manufacturer fairness concerns, *Soft Science*, 28(11) (2014) 67-71.
14. Zhang-yue Chen, Yong Wang and Xiao-yu Chen, The competition analysis of closed-loop supply chain under bidirectional fairness concerns of manufacturer, *Chinese Journal of Management*, 13(5) (2016) 772-780.
15. Zhi Liu, Bang-yi Li, Ben-gang Gong and Jin-shi Cheng, Production design decision and coordination of closed-loop supply chain considering remanufacturer's fairness concern. Control and Decision, 31(9) (2016) 1615-1622.
16. Xue-feng Ding, Fang-fang Wei and Bin Dan, Pricing and coordination mechanism of closed loop supply chain considering retailer's fairness concerns, *Computer Integrated Manufacturing System*, 20(6) (2014) 1471-1480.
17. Feng-min Yao and Chun-xian Teng, Decision models of closed-loop supply chain with dominate retailer considering fairness concerns, *Control and Decision*, 32(1) (2017) 117-123.
18. Shao-fu Du, Chan Du, Liang Liang and Tian-zhuo Liu, Supply chain coordination considering fairness concerns, *Journal of Management Sciences in China*, 13(11) (2010) 41-48.