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Fairness concerns and risk aversion on recycle pricing strategies: implications for environmentally friendly supply chains

Jianhong He, Lei Zhang, Binbin Lu, and Lin Li

Abstract

This paper studies the pricing strategy in the closed-loop supply chain with Nash bargaining when considering fairness concerns and risk aversion. Mainly, the authors argue that behavioral factors (i.e., fairness concern and risk aversion) should be introduced into pricing process. They consider three different pricing models: the first is that both manufacturer and retailer have fairness concern; the second is both manufacturer and retailer have risk aversion and the final is manufacturer has risk aversion but retailer has both risk aversion and fair concern. Then the authors analyze the model with game theory. The results show that fairness and risk aversion change the optimal pricing strategy, which affects the expected profits of retailers and manufacturers. The impact of the two (relatively irrational) behavioral factors on wholesale price and retail price of new products, as well as the recycle price and recycle transfer price of the waste products are not the same. For new products, wholesale price is the most affected by the behavioral factors, and the sales price as the second. For the waste recycling products, the transfer price is the most affected by the behavioral factors, and recycle price as the second. When facing the fairness and risk aversion retailer, retailers' fairness concern is good for both manufacturers and retailers. This innovative model for pricing strategy adds implications for sustainability in supply chain operations.

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Keywords Closed-loop supply chain; irrational behavior education; fairness concerns; risk aversion; pricing strategy

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1 Introduction

The closed-loop supply chain is formed in the decrease and the recycling of the waste. Whether the operation of the closed-loop supply chain can be effective depends on stakeholders' interest game with the focus of price, which has drawn researchers' wide attention. For the manufacture, studies have shown that the retailer recycling model is better than that of the manufacturer recycling and of the third-party recycling(Savaskan R C., et al. 2004)for price strategy of closed-loop supply chain. However, the price strategy of strategic products has a direct effect on manufacturers' recycling channels within the market structure composed by monopoly manufacturing and two competing retailers (Savaskan R C., et al. 2006). FERRER et al.(2010)studied the differentiated pricing strategy of new products and remanufactured ones in closed-loop supply chain in the multi-cycle. In this case, factors including random demand and recovery, information asymmetry and the sharing contract of supply risk are important for the price strategy and adjustment in the closed-loop supply Chain(Shi J. et al. 2011; Wei J., et al. 2015; He Y. 2017).Relatively speaking, the researches of Chinese scholars mainly focus on issues including contract coordination mechanism(Zhang Hanjiang et al. 2015; Zheng Benrong et al. 2017), channel mode choice(Lu Ronghua, Li Nan. 2016), pricing strategy (Liu Guangfu, Liu Wenxia. 2017; Yang Jie, Cao Kai. 2014)and government intervention. The research on the price strategy is based on decision-makers' being absolute reasonable.

However, as being absolute reasonable for decision-makers is usually impossible in closed-loop supply chain and this may lead to decision bias(Loch H, Wu Y. 2008; Davis M, et al. 2014), factors of individual behavior in social psychology and cognitive psychology can be applied in the research of supply chain to further study their impact on decision making. For example, fairness concerns behavior in social psychology is essential for decision-makers' profit distribution (Qu You, et al. 2017). When fairness concerns are applied, supply chain coordination can be achieved through the wholesale price contract (Cui T H, et al. 2007). The fact is, under this circumstance, problems such as the coordination, the optimal decision (Cao Erbao, Hou Limei 2016;Yao Fengmin, et al. 2017), equilibrium and competition(Chen Zhangyue, et al. 2016)can all be solved. Similar with the application of fairness concerns in social psychology, risk aversion in cognitive psychology is often applied in supply chain analysis. When risk is considered, decision makers tend to avoid possible risk in the cost of some profits (Hong Xianpei, et al. 2013). Besides, their sensitivity also has a direct impact on the optimal strategy. For example, manufacturers often apply different wholesale price strategies to deal with the risk brought by the changes of retailers' attitudes toward risk (Xu Minli, et al. 2016). In this occasion, the more risky the decision makers are, the less ordering they'll purchase (Yang Jian, Luo Chun lin. 2010). Based on this analysis, different contract mechanisms are set to coordinate the price strategy in the closed-loop supply chain (Chen Yuke, et al. 2017).

In the existing studies are mainly focused on direct impact on pricing, ordering and profits brought by decision makers' irrational behavior under the assumption that one side's behavior is somehow irrational while the other side's is absolutely rational(Li Q H, Li B. 2016;Du Shaofu, et al. 2010). However, both sides can be irrational in the closed-loop supply chain, leading to the change of the results of the price game in the closed-loop supply chain. Under the circumstance that both

sides have irrational behavior, this thesis attempts to study the price strategies in the closed-loop supply chain in the following three situations: first, both manufacturers and retailers have fairness concerns behavior; second, both manufacturers and retailers have risk aversion behavior; third, manufacturers have risk aversion behavior and retailers have both fair concerns and risk aversion behavior. Based on this, we'll analyze how these two behavioral factors will influence the optimal pricing and profit of members in the supply chain through simulation, and provide reference for the management and decision making of the closed-loop supply chain.

2 Descriptions and Assumptions

This thesis will focus on the following description: in a closed-loop supply chain composed by a manufacture and a retailer, where the manufacture is responsible for the production of new products and remanufactured ones while the retailer retails products from the manufacturer and put them into market. The retailer is entrusted by the manufacturer for recycling the waste from the consumer to the manufacturer at a set transfer price. Since usually manufacturers will receive certain government subsidies for the disposal of the waste, we consider government subsidies as a fixed income that manufacturers obtain before decision making. Therefore, the closed-loop supply chain' structure is as shown in Figure 1.

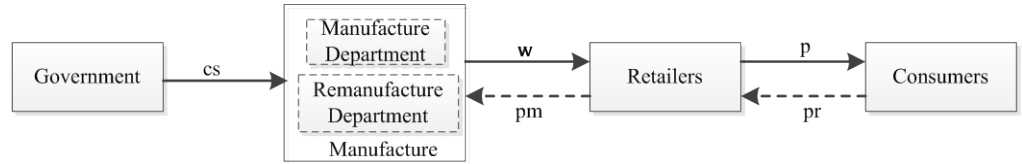


Figure1 The closed-up supply chain under government subsidies

According to the description above, assumptions and symbols of the model are as followings:

c_m is the unit cost of a manufacturer's producing a new product from new raw material, constant.

c_r is the unit cost of remanufacturing recycled products, constant. All recycled waste can be used, so the remanufacturing rate is 1, and $c_m > c_r$, $\Delta = c_m - c_r$.

p is the selling price of new products and remanufactured products, and is the retailer's decision variable, $p > c_m > c_r$.

w is the wholesale price of new products and remanufactured products for the manufacturer to the retailer and is the manufacturer's decision variable.

p_r is the price for the waste when retailers recycle it from consumers and is the retailer's decision variable.

p_m is the manufacturer's transfer price, $p_r < p_m < c_m - c_r$ (to ensure that manufacturers and retailers can obtain profits and are motivated to do so), and is the manufacturer's decision variable.

c_s is the government subsidy factor for remanufactured products, and is the manufacturer's decision variable.

D is the product demand. Suppose product demand D is a decreasing function of sales price p , that is, $D(p) = \alpha - \beta p$. Among them: α is the potential demand of the market, β is the coefficient of price elastic. Assume that the market potential demand is a random variable, and, $\alpha = \alpha_0 + \varepsilon_1$, among which the expectation of the uncertainty part, ε_1 is 0, the variance is δ_1 .

G is the supply of the waste market. Suppose the supply G is an increasing function of the recovery price p_r , $G(p_r) = a + bp_r$, among which: a is the amount of waste that consumers would volunteer to give when the recycling price 0, b is the sensitivity of consumers to the price of recovery, the greater the b , the more sensitive consumers are. Suppose a is also a random variable, and, $a = a_0 + \varepsilon_2$, the expectation of the uncertainty part ε_2 is 0, the variance is δ_2 .

Only when retailers have fairness concerns behavior, the manufacturer's optimal wholesale price is $\overline{w^{fc*}}$, the optimal recovery transfer price is $\overline{p_m^{fc*}}$ the retailer's optimal sales price is $\overline{p^{fc*}}$, the optimal return price is $\overline{p_r^{fc*}}$.

Only when retailers have risk aversion behavior, the manufacturer's optimal wholesale price is $\overline{w^{ra*}}$, and the optimal return transfer price is $\overline{p_m^{ra*}}$; the retailer's optimal sales price is $\overline{p^{ra*}}$, the optimal return price is $\overline{p_r^{ra*}}$.

Based on the assumptions above, the expected profits of manufacturers and retailers are:

$$E(\pi_M) = (w - c_m)D + (c_s + \Delta - p_m)G \quad (1)$$

$$E(\pi_R) = (p - w)D + (p_m - p_r)G$$

3 No Fairness Concerns and Risk Aversion

Supposed both the manufacturer and the retailer are risk-neutral and fair-neutral in the closed-loop supply chain. That is to say, fair distribution under risk taken and in the closed-loop supply chain is not what they concern; profit maximization is what drives their decisions. Suppose the manufacturer is the leader of the market, and the retailer, the follower. The Stackelberg game is as follows: firstly, the wholesale price w_n and the recycle price p_m of the new product are decided by the manufacturer based on the demand, and then the market price p and recycle price p_r is set immediately by the retailer.

With the backward induction method, with $\frac{\partial E(\pi_R)}{\partial p} = 0$, $\frac{\partial E(\pi_R)}{\partial p_r} = 0$, we can

get:

$$\left. \begin{aligned} p &= \frac{\alpha + w\beta}{2\beta} \\ p_r &= \frac{bp_m - a}{2b} \end{aligned} \right\} \quad (3)$$

Put(3) into $E(\pi_M)$, get the first-order partial derivatives of w and p_m , let it be 0, with(3) obtain the optimal wholesale price and the transfer price of the manufacturer:

$$\left. \begin{aligned} w^* &= \frac{\alpha + c_m\beta}{2\beta} \\ p_m^* &= \frac{(c_s + \Delta)b - a}{2b} \end{aligned} \right\} \quad (4)$$

Put(4) into(3) :

$$\left. \begin{aligned} p^* &= \frac{3\alpha + c_m\beta}{4\beta} \\ p_r^* &= \frac{(c_s + \Delta)b - 3a}{4b} \end{aligned} \right\} \quad (5)$$

Put(4) and(5) into(1) and(2) , get the expected profits of manufacturers and retailers: $E(\pi_M) = \frac{b(\alpha - c_m\beta)^2 + \beta[a + b(c_s + \Delta)]^2}{8\beta b}$

$$E(\pi_R) = \frac{b(\alpha - c_m\beta)^2 + \beta[a + b(c_s + \Delta)]^2}{16\beta b}$$

Proposition 1 Fair-neutral and risk-neutral Manufacturers and Retailers' optimal profit, the recycled price of the use products and manufacturer's transfer price will increase with the increase of government's subsidies; while the manufacturer's wholesale price and retailer's sales prices are neither related to government subsidies nor to equity concerns and risk aversion.

Proof, by

$$\frac{\partial w}{\partial c_s} = 0, \quad \frac{\partial p}{\partial c_s} = 0$$

$$\frac{\partial p_m}{\partial c_s} = \frac{1}{2} > 0, \quad \frac{\partial p_r}{\partial c_s} = \frac{1}{4} > 0, \quad \frac{\partial E(\pi_M)}{\partial c_s} = \frac{1}{4} > 0, \quad \frac{\partial E(\pi_R)}{\partial c_s} = \frac{1}{8} > 0$$

Proposition 1 shows that government subsidies for remanufacturing will help increase the recycle price, so as to increase the quantity and rate of the used and the profit of the decision makers, which is beneficial to both manufacturers and retailers themselves.

4 When fair concerns exist in both manufacturers and retailers

Equity concerns are usually demonstrated by the application of differences in earnings into the utility function, it can be shown as $U_i = \pi_i - \lambda_i (\pi_k - \pi_i)$, where U_i is the member's utility, π_i its own profit, π_k the other's profits; λ_i , the coefficient of fairness of interest, $\lambda_i \geq 0$. When $\lambda_i = 0$, the decision makers are fair and neutral; when $\pi_i \geq \pi_k$, their own utility increases with the increase of profit differences, and when $\pi_i < \pi_k$ the utility decreases with the increase of the profit difference (Du Shaofu, et al. 2010).

However, fairness is relative in reality, and both the power and contribution of decision-making will affect the fairness of income distribution. A feasible method is to construct a fairness-based framework based on Nash bargaining game theory, and then to further study the perception of fairness by both decision-makers. Based on this, the decision maker's perception of fairness is assumed as: $(\overline{\pi_R}, \overline{\pi_M})$. Then the difference in benefits is supposed to result in changes in utility, that is, $U_i = \pi_i - \lambda_i (\pi_k - \pi_i)$. With Nash bargaining game theory, we can know the fair solution here is the one for the following model:

$$\left. \begin{array}{l} \max_{\pi_R, \pi_M} U_R U_M \\ s.t. \pi_R + \pi_M = \pi, \overline{\pi_R} + \overline{\pi_M} = \pi \\ U_R, U_M > 0 \end{array} \right\} \quad (6)$$

$$\text{Get } U_R U_M (\pi_R, \pi_M) = [(1 + \lambda_r) \pi_R - \lambda_r \overline{\pi_R}] \times [(1 + \lambda_m) (\pi - \pi_R) - \lambda_m (\pi - \overline{\pi_R})]$$

$U_R U_M (\pi_R, \pi_M)$ get the second order partial derivative

$$\frac{\partial^2 (U_R U_M)}{\partial \pi_R^2} = -2(1 + \lambda_r)(1 + \lambda_m) < 0$$

So $U_R U_M (\pi_R, \pi_M)$ is a strictly concave function, there is a unique maximum $\overline{\pi_R}$, and it is applicable in the following first-order conditions of

$$\frac{\partial U_R U_M (\overline{\pi_R})}{\partial \pi_R} = 0$$

According to the fixed-point theorem, the fair solution of Nash bargaining can be obtained:

$$\begin{aligned} \overline{\pi_R} &= \frac{1 + \lambda_r}{2 + \lambda_m + \lambda_r} \pi \\ \overline{\pi_M} &= \frac{1 + \lambda_m}{2 + \lambda_m + \lambda_r} \pi \end{aligned}$$

The utility function of manufacturers and retailers of Nash's bargaining are:

$$U_R^{fc} = \frac{(1+\lambda_m)(2+\lambda_r)}{2+\lambda_m+\lambda_r} \pi_R - \frac{\lambda_r(1+\lambda_r)}{2+\lambda_m+\lambda_r} \pi_M \quad (7)$$

$$U_M^{fc} = \frac{(1+\lambda_m)(2+\lambda_r)}{2+\lambda_m+\lambda_r} \pi_M - \frac{\lambda_m(1+\lambda_m)}{2+\lambda_m+\lambda_r} \pi_R \quad (8)$$

Backwards Induction $\frac{\partial U_R^{fc}}{\partial p} = 0, \frac{\partial U_R^{fc}}{\partial p_r} = 0$, we can get

$$\left. \begin{aligned} p^{fc} &= \frac{\beta w(2+\lambda_m+\lambda_r) + (2+\lambda_m)\alpha - \beta c_m \lambda_r}{2\beta(2+\lambda_m)} \\ p_r^{fc} &= \frac{p_m b(2+\lambda_m+\lambda_r) - (2+\lambda_m)a - b(c_s + \Delta)\lambda_r}{2b(2+\lambda_m)} \end{aligned} \right\} \quad (9)$$

Put (9) into (8), we can get the first-order partial derivatives of w and p_m respectively. Suppose it is 0, we can get the optimal wholesale price and the recycle transfer price of the manufacturer.

$$\left. \begin{aligned} w^{fc*} &= \frac{\alpha(2+\lambda_m)^2 + \beta c_m [4(1+\lambda_r) + \lambda_m(2+\lambda_r)]}{\beta(4+\lambda_m)(2+\lambda_m+\lambda_r)} \\ p_m^{fc*} &= \frac{-a(2+\lambda_m)^2 + \beta c_m [4(1+\lambda_r) + \lambda_m(2+\lambda_r)]}{b(4+\lambda_m)(2+\lambda_m+\lambda_r)} \end{aligned} \right\} \quad (10)$$

Put (10) into (9) :

$$\left. \begin{aligned} p^{fc*} &= \frac{\alpha(3+\lambda_m) + \beta c_m}{\beta(4+\lambda_m)} \\ p_m^{fc*} &= \frac{-a(3+\lambda_m) + b(c_s + \Delta)}{b(4+\lambda_m)} \end{aligned} \right\} \quad (11)$$

Put (10) and (11) into (1) and (2), we can get the expected profit of both sides:

$$E(\pi_M^{fc*}) = \frac{b(\alpha - \beta c_m)^2 (2+\lambda_m)^2 + \beta [a + b(c_s + \Delta)]^2 (2+\lambda_m)^2}{\beta b(4+\lambda_m)^2 (2+\lambda_m+\lambda_r)}$$

$$E(\pi_R^{fc*}) = \frac{b(\alpha - \beta c_m)^2 (2+\lambda_m + 3\lambda_r + \lambda_m \lambda_r) + \beta [a + b(c_s + \Delta)]^2 (2+\lambda_m + 3\lambda_r + \lambda_m \lambda_r)}{\beta b(4+\lambda_m)^2 (2+\lambda_m+\lambda_r)}$$

Proposition 2 When both the manufacturer and the retailer have fairness concerns, the manufacturer's optimal wholesale price decreases as the retailer's fairness concern coefficient increases and increases with its own fairness concern coefficient. The manufacturer's recycle and transfer price increases with the increase of the retailer's fairness concern coefficient and decreases with its own fairness concern coefficient.

Proof:

$$\frac{\partial w^{fc*}}{\partial \lambda_m} = \frac{(\alpha - \beta c_m)(2 + \lambda_m)[4 + 6\lambda_r + \lambda_m(2 + \lambda_r)]}{\beta(4 + \lambda_m)^2(2 + \lambda_m + \lambda_r)^2} > 0$$

$$\frac{\partial w^{fc*}}{\partial \lambda_r} = \frac{(\beta c_m - \alpha)(2 + \lambda_m)^2}{\beta(4 + \lambda_m)(2 + \lambda_m + \lambda_r)^2} < 0$$

$$\frac{\partial p_m^{fc*}}{\partial \lambda_m} = -\frac{[a + b(c_s + \Delta)](2 + \lambda_m)[4 + 6\lambda_r + \lambda_m(2 + \lambda_r)]}{b(4 + \lambda_m)^2(2 + \lambda_m + \lambda_r)^2} < 0$$

$$\frac{\partial p_m^{fc*}}{\partial \lambda_r} = \frac{[a + b(c_s + \Delta)](2 + \lambda_m)^2}{b(4 + \lambda_m)(2 + \lambda_m + \lambda_r)^2} > 0$$

Proposition 2 shows that with the increase of the manufacturer's fairness concern coefficient, the effect of the retailer's profit on the manufacturer's utility will be greater. As a response, the manufacturer's pricing decision will be more aggressive. This will reduce the retailer's bargaining power. At this time, the manufacturer will increase the wholesale price of new products and reduce the transfer price of the waste to increase the proportion of profits in the supply chain. However, this will inevitably cause the retailers fairness concerns. Then, with the increase of the retailer's fairness concern coefficient, the manufacturer's bargaining power will be decreased, so manufacturers will then tend to conservative pricing decisions by choosing a lower wholesale price and a higher waste recycling price. Thereby the manufacturer's the proportion of profits in the supply chain is reduced.

Proposition 3 When both the manufacturer and the retailer have fairness concerns, the optimal sales price of the retailer increases with the increase of the manufacturer's fairness concern coefficient; the optimally recycle price decreases with the increase of the manufacturer's fairness concern coefficient. The retailer's sales price and recycle price will not be affected by their own fairness concern coefficient, that is to say, whether there are fairness concerns, retailers will try to improve their own profits by adjusting the sale price and transfer price.

Proof:

$$\frac{\partial p^{fc*}}{\partial \lambda_m} = \frac{\alpha - \beta c_m}{\beta(4 + \lambda_m)^2} > 0$$

$$\frac{\partial p_r^{fc*}}{\partial \lambda_m} = -\frac{a + b(c_s + \Delta)}{b(4 + \lambda_m)^2} < 0$$

$$\frac{\partial p^{fc*}}{\partial \lambda_r} = 0, \quad \frac{\partial p_r^{fc*}}{\partial \lambda_r} = 0$$

Proposition 3 shows that when both the retailer and the manufacturer have fairness concern behavior, as a market leader, the more the manufacture concern of fairness, the more likely will it be for the manufacture to increase the wholesale price and to decrease the recycle price and transfer price to increase its proportion of profits in the supply chain. As a result, the retailer's profits will be reduced. As a response, the retailer will raise sale prices and lower recycle prices to pass on the risk to consumers and increase its own profits and the proportion of profits in the supply chain.

Corollary 1 (1) $w^{fc*} > \overline{w^{fc*}}$, $w^* > \overline{w^{fc*}}$; (2) $p_m^{fc*} < \overline{p_m^{fc*}}$, $p_m^* < \overline{p_m^{fc*}}$;

$$(3) \quad p^{fc*} > \overline{p^{fc*}} = p^*, p_r^{fc*} < \overline{p_r^{fc*}} < p_r^*; (4) \quad Q^{fc*} < Q^*, G^{fc*} < G^*$$

Prove that when and only when retailers have fairness concerns, $\lambda_m = 0$, $w^{fc*} = \frac{\alpha + \beta c_m (1 + \lambda_r)}{\beta (2 + \lambda_r)} = \overline{w^{fc*}}$, we can see that w^{fc*} is an increasing function of λ_m , so $w^{fc*} > \overline{w^{fc*}}$ ($0 < \lambda_m < 1$). Similarly, we can know, $p_m^{fc*} < \overline{p_m^{fc*}}$, $p^{fc*} > \overline{p^{fc*}}$, $p_r^{fc*} < \overline{p_r^{fc*}}$.

Corollary 1 shows that when and only when the manufacture has fairness concerns, the optimal wholesale price of manufacturers should be under should under that of the rational optimality and that when both the sides have fairness concerns while the optimal recycle and transfer price should be higher than that of the rational optimality and that when both the sides have fairness concerns. This is because the bargaining power of manufacturers is starkly weakened when and only when retailers have a fairness concern behavior, so manufacturers will tend to reduce the wholesale price and raise the recycle and transfer price, which will increase retailers' profits. When both retailers and manufacturers have fairness concerns, the retailer's optimal sales price will be higher while the retailer's optimal recycle price will be lower than that of the rational optimality and that when only retailers have fairness concerns. Sales volume is a decreasing function of sales price while recycle volume is an increasing one of recycle price. So when both retailers and manufacturers have fairness concern behavior, the optimal sales volume and the optimal recycle volume will both be less than that of the rational optimality.

5 When both manufacturers and retailers have risk aversion

Risk aversion refers to the decisions of a company are made to avoid risks and so caused losses (Ye Fei, Lin Qiang.2012). As is shown in many studies(Choi TM. 2002), the objective utility function that is applied to characterizes risk aversion behavior is:

$$U^{aversion}(\pi) = E(\pi) - \eta_i Var(\pi)$$

η_i means the risk aversion of decision makers. When $\eta_i > 0$, indicating that the policy-makers are risk-averse; $\eta_i = 0$, risk-neutral, and the expected utility of the policy maker equals the expected profit.

Based on the research, the expected utility function for retailers and manufacturers is:

$$U_R^{ra} = (p - w)(\alpha - \beta p) + (p_m - p_r)(a + bp_r) - \eta_r [(p - w)\delta_1 + (p_m - p_r)\delta_2] \quad (12)$$

$$U_M^{ra} = (w - c_m)(\alpha - \beta p) + (c_s + \Delta - p_m)(a + bp_r) - \eta_m [(w - c_m)\delta_1 + (c_s + \Delta - p_m)\delta_2] \quad (13)$$

According to Backwards Induction, (13) carries out the first-order derivation of p and p_r respectively, $\frac{\partial U_R^{ra}}{\partial p} = 0$, $\frac{\partial U_R^{ra}}{\partial p_r} = 0$, we can get:

$$\left. \begin{aligned} p^{ra} &= \frac{\alpha + w\beta - \eta_r \delta_1}{2\beta} \\ p_r^{ra} &= \frac{bp_m - a + \eta_r \delta_2}{2b} \end{aligned} \right\} \quad (14)$$

Put (14) into (13), we can get the first-order partial derivatives of w and p_m , respectively, then suppose it is 0, with (14) we can know the optimal wholesale price and the transfer price of the manufacturer

$$\left. \begin{aligned} w^{ra*} &= \frac{\alpha + c_m \beta + \eta_r \delta_1 - 2\eta_m \delta_1}{2\beta} \\ p_m^{ra*} &= \frac{-a + b(c_s + \Delta) - \eta_r \delta_2 + 2\eta_m \delta_2}{2b} \end{aligned} \right\} \quad (15)$$

Put (15) into (14) :

$$\left. \begin{aligned} p^{ra*} &= \frac{3\alpha + c_m + \beta - \eta_r \delta_1 + 2\eta_m \delta_1}{4\beta} \\ p_r^{ra*} &= \frac{-3a + b(c_s + \Delta) + \eta_r \delta_2 - 2\eta_m \delta_2}{4b} \end{aligned} \right\} \quad (16)$$

$$D^{ra*} = \frac{\alpha - c_m \beta + \eta_r \delta_1 + 2\eta_m \delta_1}{4}$$

$$G^{ra*} = \frac{a + b(c_s + \Delta) + \eta_r \delta_2 + 2\eta_m \delta_2}{4}$$

$$\text{The optimal sales volume: } Q^{ra*} = \frac{\alpha - \beta c_m + \eta_r \delta_1 + 2\eta_m \delta_1}{4}$$

$$\text{The optimal recycle volume: } G^{ra*} = \frac{a + b(c_s + \Delta) + \eta_r \delta_2 + 2\eta_m \delta_2}{4}$$

Put (16) and (15) into (1) and (2), we can get the expected profits of manufacturers and retailers and that of the whole supply chain:

$$E(\pi_M^{ra*}) = \frac{b\{[(\alpha - \beta c_m) + \eta_r \delta_1]^2 - 4(\eta_m \delta_1)^2\} + \beta\{[a + b(c_s + \Delta) + \eta_r \delta_2]^2 - 4(\eta_m \delta_2)^2\}}{8\beta b}$$

$$+ \frac{b\{[(\alpha - \beta c_m) + 2\eta_m \delta_1]^2 - 3(\eta_r \delta_1)^2 - 2\eta_r \delta_1[(\alpha - \beta c_m) + 2\eta_m \delta_1]\} + \beta\{[a + b(c_s + \Delta) + 2\eta_m \delta_2]^2 - 3(\eta_r \delta_2)^2 - 2\eta_r \delta_2[a + b(c_s + \Delta) + 2\eta_m \delta_2]\}}{16\beta b}$$

Proposition 6 When both the manufacturer and the retailer have risk aversion behavior, the manufacturer's optimal wholesale price decreases with the increase of the manufacturer's risk aversion coefficient η_m and the market potential demand variance δ_1 , while increase with the increase of the retailer's risk aversion coefficient η_r and the market potential demand variance δ_1 the manufacturer's optimal recycle and transfer price increases with the increase of the manufacturer's risk aversion coefficient η_m and the market potential demand

variance δ_2 , while increase with the increase of the retailer's risk aversion coefficient η_r and the market potential demand variance δ_2 .

Proof:

$$\frac{\partial w^{ra*}}{\partial \eta_m \delta_1} = -\frac{1}{\beta} < 0, \frac{\partial w^{ra*}}{\partial \eta_r \delta_1} = \frac{1}{2\beta} > 0$$

$$\frac{\partial p_m^{ra*}}{\partial \eta_m \delta_2} = \frac{1}{b} > 0, \frac{\partial p_m^{ra*}}{\partial \eta_r \delta_2} = -\frac{1}{2b} < 0$$

Proposition 6 shows that with the increase of risk aversion increases, as the market leader, on the one hand, the manufacture will reduce the wholesale price to lower retailers' sale price and increase the sales volume. In this way, the risk will be transferred to retailers. On the other hand, the manufacturer will increase the recycle and transfer price to encourage retailers to provide more used products to improve recycle and remanufacturing volume, through which the manufacture can gain more profits and make up for part of the positive market loss. At the same time, with the increase of retailers' risk aversion, manufacturers will take the opportunity to increase the wholesale price and reduce the recycle and transfer price for more profits and higher proportion of profits in the supply chain.

Proposition 7 When both the manufacturer and the retailer have risk aversion, the optimal sales price of the retailer decreases with the increase of the retailer's risk aversion coefficient η_r and the potential demand variance δ_1 , it also decreases with the 's increase of the manufactures risk aversion coefficient η_m and the potential demand variance δ_1 . The optimal recycle price of the retailer increases with the increase of the manufacture's risk aversion coefficient η_m and the potential demand of the market for the waste variance δ_2 . And it increases with the increase of the retailer's risk aversion coefficient η_r and the potential demand of the market for the waste variance δ_2 .

Proof:

$$\frac{\partial p^{ra*}}{\partial \eta_r \delta_1} = -\frac{1}{4\beta} < 0, \frac{\partial p^{ra*}}{\partial \eta_m \delta_1} = -\frac{1}{2\beta} < 0$$

$$\frac{\partial p_r^{ra*}}{\partial \eta_m \delta_2} = \frac{1}{2b} > 0, \frac{\partial p_r^{ra*}}{\partial \eta_r \delta_2} = \frac{1}{4b} > 0$$

Proposition 7 shows that as retailers increase their risk aversion, retailers, on the one hand, reduce the positive returns on the one hand by reducing the sales price of new products, encouraging consumers to buy more new products, increasing the sales of new products, Risk; on the other hand, the more afraid retailers are at risk, for their own benefit, the higher the price of recycling waste products from consumers, increasing the recovery of waste products. When the risk aversion of the manufacturer increases, the manufacturer will, according to his own interests, raise the price of recycling and transfer, so that the retailer can

also raise the recovery price so as to obtain more benefits from the recycling of waste products.

Corollary 2 (1) $p^{ra*} < \overline{p^{ra*}} < p^*$; (2) $p_r^{ra*} > \overline{p_r^{ra*}} > p_r^*$; (3) $w^{ra*} < \overline{w^{ra*}}$, $w^* < \overline{w^{ra*}}$;

(4) $p_m^{ra*} > \overline{p_m^{ra*}}$, $p_m^* > \overline{p_m^{ra*}}$

Prove that when only retailers have risk aversion behavior, that is $\eta_m = 0$ then the manufacturer's wholesale price is $w^{ra*} = \frac{\alpha + c_m\beta + \eta_r\delta_1}{2\beta} = \overline{w^{ra*}}$, from

proposition 6, we know w^{ra*} a decreasing function of η_m , $\overline{w^{ra*}} < w^{ra*}$ ($0 < \eta_m < 1$), $\overline{w^{ra*}}$ an increasing function of η_r , so $w^* < \overline{w^{ra*}}$. Similarly, $p^{ra*} < \overline{p^{ra*}} < p^*$, $p_r^{ra*} > \overline{p_r^{ra*}} > p_r^*$, $p_m^{ra*} > \overline{p_m^{ra*}}$, $p_m^* > \overline{p_m^{ra*}}$.

Corollary 2 shows that when sides have risk aversion, the retailer's optimal sales price is lower than the optimal sales price when and only when retailers have risk aversion. The optimal recycle price is higher than the optimal one when and only when retailers have risk aversion. This is because with the increase of risk aversion of both sides, retailers, in order to protect their own interests, will further reduce the sales prices to promote selling and increase the recycle price to obtain more profits. When only retailers with risk aversion, the manufacturer's optimal wholesale price is higher than that when both sides have risk aversion and the rational optimal one, while the recycle price is lower. This is because when only the retailer has risk aversion, manufacturers increase the wholesale price to control its price-cutting, to increase their wholesale price while reduce the recycle price for more profits.

Proposition 8 (1) $p^{fc*} > p^* > p^{ra*}$; (2) $p_r^{fc*} < p_r^* < p_r^{ra*}$; (3) $Q^{fc*} < Q < Q^{ra*}$;

(4) $G^{fc*} < G < G^{ra*}$

Proof:

$$(1) p^* = \frac{3\alpha + c_m\beta}{4\beta}$$

$$p^{fc*} - p^* = \frac{(\alpha - \beta c_m)\lambda_m}{4\beta(4 + \lambda_m)} > 0, \quad p^{ra*} - p^* = -\frac{\eta_r\delta_1 + 2\eta_m\delta_1}{4\beta} < 0, \quad \text{so } p^{fc*} > p^* > p^{ra*}$$

$$(2) p_r^* = \frac{(c_s + \Delta)b - 3a}{4b}$$

$$p_r^{fc*} - p_r^* = -\frac{[a + b(c_s + \Delta)]\lambda_m}{4b(4 + \lambda_m)} < 0, \quad p_r^{ra*} - p_r^* = \frac{\eta_r\delta_2 + 2\eta_m\delta_2}{4b} > 0, \quad \text{so } p_r^{fc*} < p_r^* < p_r^{ra*}$$

$$(3) \quad Q^* = \frac{\alpha - \beta c_m}{4}$$

$$Q^{fc*} - Q^* = \frac{\lambda_m (\beta c_m - \alpha)}{4 + \lambda_m} < 0, \quad Q^{ra*} - Q^* = \frac{\eta_r \delta_1 + 2\eta_m \delta_1}{4\beta} > 0, \quad \text{so } Q^{fc*} < Q < Q^{ra*}$$

$$(4) \quad G^* = \frac{a + b(c_s + \Delta)}{4}$$

$$G^{fc*} - G^* = -\frac{\lambda_m [a + b(c_s + \Delta)]}{4 + \lambda_m} < 0, \quad G^{ra*} - G^* = \frac{\eta_r \delta_2 + 2\eta_m \delta_2}{4} > 0, \quad \text{so } G^{fc*} < G < G^{ra*}$$

Proposition 8 shows that fairness concerns and risk aversion change the pricing strategies of manufacturers and retailers. When both sides have fair and responsible behavior, they play a positive role in the retailer's sales price and have a negative effect on the recycle price. In order to obtain greater benefits, the rationality is maximized. However, when both sides have risk aversion, they both play a negative role in the pricing of the retailer's sales and at the same time play a positive role in the recycle price. Therefore, based on the rational optimal, to improve the sales price and the optimal recycle price. Because sales volume is a decreasing function of sales price, the recycle volume is an increasing function of the recycle price, so the optimal sales volume and the optimal recycle volume under the risk aversion of both sides will be the largest.

6 Manufacturers have risk aversion and retailers have fairness concerns and risk aversion

The equity concerns function and loss avoidance function for retailers can be shown as $E(\pi_R)^\pm$ with additional effects. Similarly, the total expected utility function when retailers have fairness concerns and risk aversion can be shown as $E(\pi_R)^\pm$ with additional effects :

$$\begin{aligned} U_R^{fr} &= \frac{2(1+\lambda_r)}{2+\lambda_r} \pi_R - \frac{\lambda_r(1+\lambda_r)}{2+\lambda_r} \pi_M - \eta_r \text{Var}(\pi_R) \\ &= \frac{2(1+\lambda_r)}{2+\lambda_r} \pi_R - \frac{\lambda_r(1+\lambda_r)}{2+\lambda_r} \pi_M - \eta_r [(p-w)\delta_1 + (p_m - p_r)\delta_2] \end{aligned} \quad (17)$$

When $\lambda_r > 0$, $\lambda_m = 0$, the manufacturer's expected utility function is

$$\begin{aligned} U_M &= E(\pi_M) - \eta_m \text{Var}(\pi_M) = \\ &= (w - c_m)(\alpha - \beta p) + (c_s + \Delta - p_m)(a + bp_r) - \eta_m [(w - c_m)\delta_1 + (c_s + \Delta - p_m)\delta_2] \end{aligned} \quad (18)$$

According to Backwards Induction, (17) carries out the first-order derivation of p and p_r respectively, $\frac{\partial U_R^{fr}}{\partial p} = 0$, $\frac{\partial U_R^{fr}}{\partial p_r} = 0$, we can get:

$$\left. \begin{aligned} p^{fr} &= \frac{(2+\lambda_r)(1+\lambda_r)(\alpha+\beta w)-\lambda_r(1+\lambda_r)(\alpha+\beta c_m)-\eta_r\delta_1(2+\lambda_r)}{4\beta(1+\lambda_r)} \\ p_r^{fr} &= \frac{(2+\lambda_r)(1+\lambda_r)(p_m b-a)-\lambda_r(1+\lambda_r)[(c_s+\Delta)b-a]+\eta_r\delta_2(2+\lambda_r)}{4b(1+\lambda_r)} \end{aligned} \right\} \quad (19)$$

Put (19) into (18), we can get the first order partial derivative of w and p_m , put it as 0, then with (18) we can get the optimal wholesale price and recycle and transfer price of the manufacture:

$$\left. \begin{aligned} w^{fr*} &= \frac{2\alpha(1+\lambda_r)+2\beta c_m(1+\lambda_r)^2+\eta_r\delta_1(2+\lambda_r)-4\eta_m\delta_1(1+\lambda_r)}{2\beta(2+\lambda_r)(1+\lambda_r)} \\ p_m^{fr*} &= \frac{-2a(1+\lambda_r)+2b(1+\lambda_r)^2(c_s+\Delta)-\eta_r\delta_2(2+\lambda_r)+4\eta_m\delta_2(1+\lambda_r)}{2b(2+\lambda_r)(1+\lambda_r)} \end{aligned} \right\} \quad (20)$$

Put (20) into (19), we can get:

$$\left. \begin{aligned} p^{fr*} &= \frac{6\alpha(1+\lambda_r)+2\beta c_m(1+\lambda_r)-4\eta_m\delta_1(1+\lambda_r)-\eta_r\delta_1(2+\lambda_r)}{4\beta(1+\lambda_r)} \\ p_r^{fr*} &= \frac{-6a(1+\lambda_r)+2b(1+\lambda_r)(c_s+\Delta)+4\eta_m\delta_2(1+\lambda_r)+\eta_r\delta_2(2+\lambda_r)}{4b(1+\lambda_r)} \end{aligned} \right\}$$

The optimal sales volume:

$$Q^{fr*} = \frac{-2\alpha(1+\lambda_r)-2\beta c_m(1+\lambda_r)+4\eta_m\delta_1(1+\lambda_r)+\eta_r\delta_1(2+\lambda_r)}{4(1+\lambda_r)}$$

The optimal recycle volume:

$$G^{fr*} = \frac{-2a(1+\lambda_r)+2b(c_s+\Delta)(1+\lambda_r)+\eta_r\delta_2(2+\lambda_r)+4\eta_m\delta_2(1+\lambda_r)}{4(1+\lambda_r)}$$

Proposition 9 When the manufacturer has risk aversion behavior and the retailer has both fairness concerns and risk aversion behavior, the optimal wholesale price of the manufacturer increases with the increase of the retailer's risk aversion coefficient η_r and potential demand variance δ_1 , while the optimal wholesale price of the manufacturer decreases with the increase of the manufacture's risk aversion coefficient η_m and potential demand variance δ_1 . When: $2(\beta c_m - \alpha)(1+\lambda_r)^2 - \eta_r\delta_1(2+\lambda_r)^2 + 4\eta_m\delta_1(1+\lambda_r)^2 < 0$, the optimal wholesale price of the manufacturer decreases with the increase of the retailer's fairness concern coefficient λ_r .

Proof:

$$\frac{\partial w}{\partial \eta_r \delta_1} = \frac{1}{2\beta(1+\lambda_r)} > 0, \quad \frac{\partial w}{\partial \eta_m \delta_1} = -\frac{2}{\beta(2+\lambda_r)} < 0$$

$$\text{when } 2(\beta c_m - \alpha)(1+\lambda_r)^2 - \eta_r\delta_1(2+\lambda_r)^2 + 4\eta_m\delta_1(1+\lambda_r)^2 < 0, \quad \frac{\partial w^{fr*}}{\partial \lambda_r} < 0.$$

Proposition 9 shows that compared with the situation when both sides have risk aversion, the retailer's fairness concerns do not change the trend of the manufacturer's optimal wholesale price adjustment with the changes of the risk aversion coefficient for both sides. When retailers are clearly concerned with the risk aversion, the wholesale price of the manufacture will decrease as a result of the reduced bargaining power.

Proposition 10 When manufacturers have risk aversion, retailers have fairness concerns and risk aversion, the retailer's optimal sales price increases with the increase of its fairness concern coefficient λ_r , while it decreases with the increases of retailers' risk aversion coefficient η_r and the potential demand variance δ_1 decreases with the increases of manufactures' risk aversion coefficient η_m and the potential demand variance δ_1 . The retailer's optimal recycle price decreases with the increase of its fairness concern coefficient λ_r , and increases with the increases of the its risk aversion coefficient η_r , the potential demand variance δ_2 . the increases of the manufactures' risk aversion coefficient η_m the potential demand variance δ_2 .

Proof:

$$\frac{\partial p^{fr*}}{\partial \lambda_r} = \frac{\eta_r \delta_1}{8\beta(1+\lambda_r)^2} > 0$$

$$\frac{\partial p^{fr*}}{\partial \eta_m \delta_1} = -\frac{1}{2\beta} < 0, \quad \frac{\partial p^{fr*}}{\partial \eta_r \delta_1} = -\frac{2+\lambda_r}{8\beta(1+\lambda_r)} < 0$$

$$\frac{\partial p_r^{fr*}}{\partial \lambda_r} = -\frac{\eta_r \delta_2}{8b(1+\lambda_r)^2} < 0$$

$$\frac{\partial p_r^{fr*}}{\partial \eta_m \delta_2} = \frac{2+\lambda_r}{2b(1+\lambda_r)} > 0, \quad \frac{\partial p_r^{fr*}}{\partial \eta_r \delta_2} = \frac{2+\lambda_r}{8b(1+\lambda_r)} > 0$$

Proposition 10 shows that compared with the situation when both sides have risk aversion, the retailer's fairness concerns do not change the trend of the adjustment for the optimal wholesale price and recycle price with the changes of the risk aversion coefficient for both sides. The fact is, with the increase of retailers' fairness concern coefficient, its bargaining power increases, so retailers will increase its proportion of profits in the supply chain by increasing sale price and reducing recycle price. That's why when both fairness concerns and risk aversion exist, retailers should know which element's influence is greater.

Proposition 11 (1) $w^{fr*} < w^{ra*}$ (2) $p^{fr*} > p^{ra*}$

Proof

$$w^{fr*} - w^{ra*} = \frac{-\lambda_r \alpha (1+\lambda_r) + \lambda_r \beta c_m (1+\lambda_r) - \lambda_r \eta_r \delta_1 (2+\lambda_r) + 2\lambda_r \eta_m \delta_1 (1+\lambda_r)}{2\beta(2+\lambda_r)(1+\lambda_r)} < 0, \quad ,$$

$$w^{fr*} < w^{ra*}$$

$$p^{fr*} - p^{ra*} = \frac{3\alpha(1+\lambda_r) + \beta c_m(1+\lambda_r) - 2\eta_m \delta_1(1+\lambda_r) - \eta_r \delta_1}{8\beta(1+\lambda_r)} > 0, p^{fr*} > p^{ra*}$$

Proposition 11 shows that fairness concerns' effect on the optimal price strategy for manufacturers and retailers is more direct than risk aversion. The optimal wholesale price of the manufacturer is inversely proportional to the retailer's fairness concern coefficient s , so the optimal wholesale price will be lower than when both sides have risk aversion. The optimal sales price of the retailer is directly proportional to the retailer's fairness concern coefficient s , so the optimal sales price is higher than when both sides have risk aversion.

Proposition 12 For both manufacturers and retailers, either fairness concerns or risk aversion is concerned, for new products, the wholesale price will be the most apparently affected, followed by the sale price; while for the used products, the transfer price will be the most apparently affected, followed by the recycle price.

Proof (3) is the optimal reaction function for retailers when the wholesale price and the recycle price is given. $\frac{\partial p}{\partial w} = \frac{1}{2}$, $\frac{\partial p_r}{\partial p_m} = \frac{1}{2}$, And based on the derivation method of composition function

$$\frac{\partial p}{\partial \lambda} = \frac{\partial p}{\partial w} \frac{\partial w}{\partial \lambda} = \frac{1}{2} \frac{\partial w}{\partial \lambda} < \frac{\partial w}{\partial \lambda}$$

$$\frac{\partial p}{\partial \eta \delta} = \frac{\partial p}{\partial w} \frac{\partial w}{\partial \eta \delta} = \frac{1}{2} \frac{\partial w}{\partial \eta \delta} < \frac{\partial w}{\partial \eta \delta}$$

$$\frac{\partial p_r}{\partial \lambda} = \frac{\partial p_r}{\partial p_m} \frac{\partial p_m}{\partial \lambda} = \frac{1}{2} \frac{\partial p_m}{\partial \lambda} < \frac{\partial p_m}{\partial \lambda}$$

$$\frac{\partial p_r}{\partial \eta \delta} = \frac{\partial p_r}{\partial p_m} \frac{\partial p_m}{\partial \eta \delta} = \frac{1}{2} \frac{\partial p_m}{\partial \eta \delta} < \frac{\partial p_m}{\partial \eta \delta}$$

7 Data simulation

To better explain the application of the model, we will test the utility model under the influence of factors mentioned above with numerical simulation to show how the fairness concerns and risk aversion can affect the optimal price and profit in the closed-loop supply chain.

Suppose the product demand function is $D(p) = 100 - 5p$, the function of the recycle volume is $G(p_r) = 10 + 20p_r$, the unit production cost of new products $c_m = 10$, the cost of remanufacturing $c_r = 6$, the government subsidies $c_s = 1$. λ and η belongs to $[0,1]$. Take the situation when both sides are risk neutral and fair neutral as reference.

The horizontal axis in Figure 2 is the manufacturer's profit when it's fair neutral. As can be seen from Figure 1, when both sides have fairness concerns, the profit of the manufacturer decreases with the increase of retailer's fairness concern coefficient. When the fairness concern coefficient s is relatively low, the profit of

the manufacturer decreases with the increase of its own fairness concern coefficient; while when the fairness concern coefficient becomes higher, the profit of the manufacturer increases with the increase of its own fairness concern coefficient. However low retailer's fairness concern coefficient (>0), and however high manufactures' fairness concern coefficient (<1), when both sides have fairness concerns, manufactures' profit is lower than when fair-neutral. When manufactures' fairness concern coefficient is 0, that is to say, when and only when retailers have fairness concerns, manufactures' profit will be lower than that when they are fair-neutral but higher than when both sides have fairness concerns.

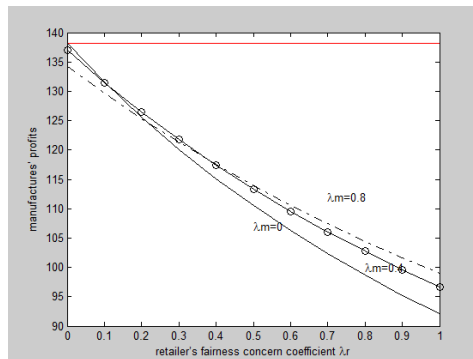


Figure 2 The effects of fairness concern coefficient on manufactures' profits

The line parallel to the horizontal axis in Figure 3 is the retailer's profit when it is fair-neutral. From Figure 2, we can see that under the parameter above, when both sides have fairness concerns, the retailer's profit increases with the increase of the retailers' fairness concern coefficient while it decreases with the increase of the manufactures' fairness concern coefficient. When retailers' fairness concern coefficient is relatively low, the profit of the retailer is lower than that of fair-neutral, but with the increase of retailers' fairness concern coefficient, the profit will be higher. When manufactures' fairness concern coefficient is relatively low, the profit of the retailer is higher than that of fair-neutral, but with the increase of manufactures' fairness concern coefficient, the profit will be lower. When manufactures' fairness concern coefficient is 0, that is to say, when and only when retailers have fairness concerns, manufactures' profit will be higher than when they are fair-neutral but higher than when both sides have fairness concerns.

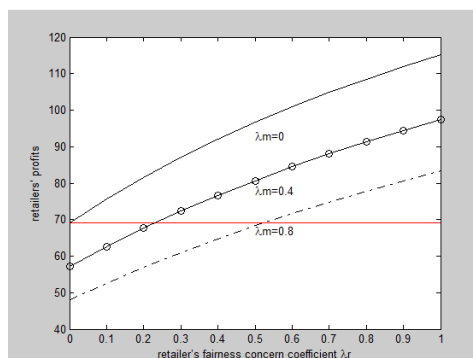


Figure 3 The effects of fairness concern coefficient on retailers' profits

The line parallel to the horizontal axis in Figure 4 is manufacturers' profit when its risk-neutral. As can be seen from Figure 3, under the parameter above, when both sides have risk aversion, the profit of manufacturer increases with the increase of retailers' risk aversion coefficient, while decreases with the increase of manufactures' risk aversion coefficient. However high both sides' fairness concern coefficient are(<1) , manufactures' profit will be lower than when they are risk-neutral. When manufactures' fairness concern coefficient is 0, that is to say, when and only when retailers have fairness concerns, manufactures' profit will be higher than when they are risk-neutral and when both sides have risk concerns.

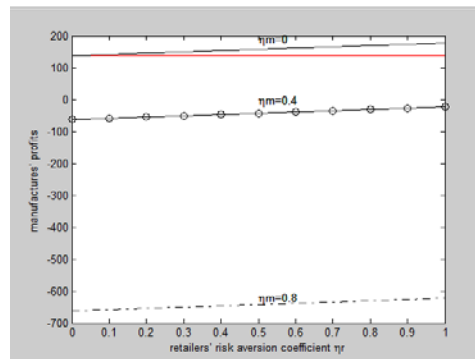


Figure 4 The effects of risk aversion coefficient on manufactures' profits

The line parallel to the horizontal axis in Figure 5 is the retailer's profit when it's risk neutral. From the figure 4, we can see that under the parameter above, when both sides have risk aversion, retailers' profit decreases with the increase of retailers' risk aversion coefficient, while increases with the increase of manufactures' risk aversion coefficient. When retailers' risk aversion coefficient is relatively low, the profit of the retailer is higher than that of risk-neutral, but with the increase of retailers' risk aversion coefficient, the profit will be lower. When manufactures' risk aversion coefficient is relatively low, the profit of the retailer is lower than that of risk-neutral, but with the increase of manufactures' risk aversion coefficient, the profit will be higher. When manufactures' risk aversion coefficient is 0, that is to say, when and only when retailers have risk aversion, manufactures' profit will be lower than when it's risk-neutral and when both sides have risk aversion.

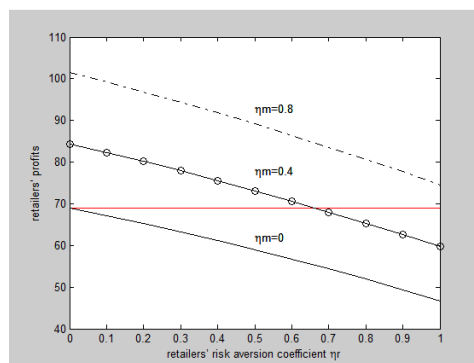


Figure 5 The effects of risk aversion coefficient on retailers' profits

The line parallel to the horizontal axis in Figure 6 is the manufacturer's profit when it is fair-neutral and risk-neutral. As can be seen from Figure 5,

under the parameter above, when the manufacturer has the risk aversion and the retailer has both risk aversion and fairness concerns, the profit of the manufacturer increases with the increase of the retailers' risk aversion coefficient, decreases with the increase of manufactures' risk aversion coefficient, and increases with the increase of retailers' coefficient of equity concern. That is to say, the change of retailers' coefficient of equity concern positively affects manufacturers' profit. For manufacturers, their profit will be higher when the retailer's risk coefficient of aversion and the fairness concern coefficient s are higher and its own risk aversion coefficient is lower.

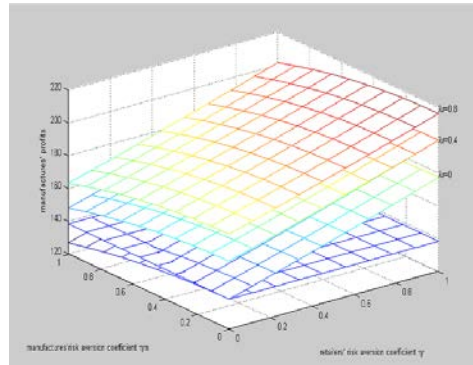


Figure 6 The effects of risk aversion coefficient and fairness concern coefficient on manufactures' profits

The line parallel to the horizontal axis in Figure 7 is the retailer's profit when it is fair-neutral and risk-neutral. As can be seen from Figure 6, under the parameter above, when the manufacturer has risk aversion and the retailer has risk aversion and fairness concern, the retailer's profit decreases with the increase of the retailer's risk aversion coefficient, and increases with the increase of retailers' fairness concern coefficient. For retailers, their profit will be higher when the manufacture's risk coefficient of aversion and its own fairness concern coefficient are higher and its own risk aversion coefficient is lower.

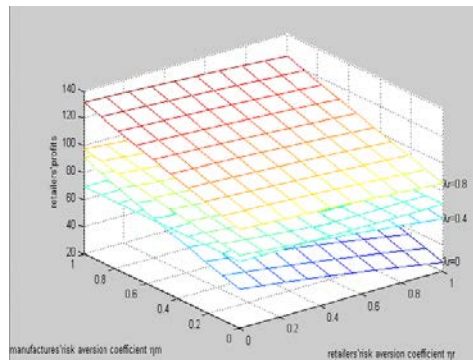


Figure 7 The effects of risk aversion coefficient and fairness concern coefficient on retailers' profits

8 Data simulation

In this paper, fairness concerns and risk aversion are applied into the analysis of the price strategy in the closed-loop supply chain. Three situations are discussed: both

manufacturers and retailers have fairness concerns, □ both manufacturers and retailers have risk aversion, □ Manufacturer have risk aversion and retailers have both risk aversion and fairness concern. The effects of the two irrational factors: fairness concerns and risk aversion, and their effects on the price strategy and profits in the closed-loop supply chain. The results show that risk aversion and fairness concerns can change the price strategy of wholesale price, transfer price, sale price and recycle price, and affects the expected profits of retailers and manufacturers. Specifically speaking, when both sides have fairness concerns, the optimal sale price in the supply chain is the highest. When both sides have risk aversion, the optimal recycle price in the supply chain is the highest. When both sides have fairness concerns, the manufacturer's optimal wholesale price will not always be higher than the rational optimal wholesale price, and the optimal transfer recycle price will not always be lower than the rational optimal one. When both sides have risk aversion, the manufacturer's optimal wholesale price will not always be lower than the rational optimal wholesale price, and the optimal transfer and recycle price will not always be higher than the rational optimal one.

The research also shows that the effects vary of irrational factors in the closed-loop supply chain on the wholesale price, sale price of new products, and the recycle price and transfer price of the used products. The wholesale price of new products is the most affected one, followed by the sale price is the second. The transfer price is the most affected one followed by the recycle price. When the manufacturer has risk aversion and the retailer has both risk aversion and fairness concerns, the retailer fairness concerns have positive effects on both sides. For the simplicity of the model, this thesis mainly discussed two irrational factors. For further research, more factors can be included to further analyze how they affect the price strategy and various recycle channels.

Academically, the paper contributes to the literature by: a. proposing a model to explore how manufacturers and retailers to price when considering fairness concerns and risk aversion in the closed-loop supply chain; b. showing the results that two irrational factors: fairness concerns and risk aversion play an important role in the pricing decision of closed-loop supply chain; and c. demonstrating that the effects of irrational factors vary when they play effect on the different stage of pricing in the closed-loop supply chain.

Practically, the analytical model introduced offers anatomy in sustainable operation of a close-loop supply chain. Sustainable operation of a supply chain depends on continuous and positive interactions (i.e., actions-responses) among member organizations (e.g., manufacturer and retailers). By incorporating the two irrational factors to existing literature, practitioners now can make more complete consideration when setting up a pricing strategy (a critical kind of action) that may affect the following responses, then more actions-responses again. In such way, the continuity or discontinuity of inter-organizational interactions would in turn determine the sustainability or corruption of a supply chain system.

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