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Research on Closed Loop Supply Chain with Dual-Channel under Consumer Awareness

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Abstract. In this paper, we study the problem of the closed-loop supply chain management mode of the dual-channel recycling e-waste by both manufacturers and retailers participated in recycling, which is considered under the environmental awareness of consumers. And then we obtain manufacturer and retailer's optimal strategy, consumer optimal environmental awareness and the manufacturer's optimal transfer price in the case of independent decision and cooperative decision. Furthermore, through a numerical calculation example, we analyze the effect of consumer awareness of environmental protection for the optimal strategy. Thus, we can obtain that the model is a reasonable and dual channel cooperation decision which is the ideal decision for the recycling of electronic waste under the consumer awareness of environmental protection.

Keywords: Consumer awareness, closed loop supply chain, dual channel recovery, transfer- price

AMS Mathematics Subject Classification (2010): 03C98, 91A10, 91A80

1. Introduction

With the increasing shortage of global resources, the growing-number of people pay attention to the recycling of used products. The world has introduced laws and regulations, requiring enterprises to recycle of waste products, such as the EU's "Waste Electrical and Electronic Equipment (WEEE)" directive, Japan's "household appliances recycling law" and China's "waste electrical and electronic products recycling management regulations" and so on. The common feature of these laws is the extensive application of the Extended Producer Responsibility (EPR), which requires the extension of producer responsibility to the entire life cycle of the product being produced, including the recycling and remanufacturing of waste products. On the other hand, with the government's continuous promotion of green consumption patterns, consumers are also concerned about the environmental performance of products and the specific treatment. Data showed that 67% of consumers in the United States believe that the purchase of environmentally friendly products is very important, and 51% of consumers are willing to pay higher prices to buy environmentally friendly products. In 2005, 31% of consumers in Europe are willing to pay high prices to buy environmentally friendly products, and in 2008 this data increased to 75%. Therefore, it is of great theoretical and practical significance to introduce the environmental awareness of consumers as an important factor in the research of the double-channel recycling closed-loop supply chain coordination

Many scholars have studied the recovery of electronic waste. Liu researched the formal channels oriented by recycling processor which has dismantling of the qualification and the non-formal channels oriented by recycling processor which has non-dismantling of the qualification. Depicted the two channels of their own recycling and profitability model, they obtained the equilibrium recovery price and renovation ratio. Zhang studied the recovery and sales pricing strategy of closed-loop supply chain system under the condition of two kinds of recycling channels. Zhou researched the impact of government's recycling regulations on the dual channel marketing closed-loop supply chain. An et al. considered the dual-channel recycling model in which manufacturers and retailers were also involved in recycling, and the prices recovered by the manufacturer from the retailer were directly used as the manufacturer's decision variables. Moreover, they studied the impact of government intervened on the dual channel sales and recycling closed-loop supply chain, and they also proposed an improved two-part pricing contract to coordinate the dual-channel closed-loop supply chain under the government's intervention [1]. Wang [7] discussed the double-channel recycling of closed-end supply chain management model. Lin et al. [8] have considered the closed-loop supply chain with dual sales channels and double recycling channels, and they established a closed-loop supply chain pricing model based on the manufacturer and retailer as the game leader. According to the production inventory, distribution inventory, customer virtual inventory and recovery inventory, Zhang established a dual-channel closed-loop supply chain dynamic model, and he obtained the robust control strategy and linear matrix inequality algorithm for solving the dynamic model of closed channel in double channel [9]. Xiong et al. [10] applied the consumer awareness of environmental factors to discuss the manufacturer's optimal recovery model and the impact consumer awareness of environmental on the optimal solution in the closed-loop supply chain. Ma studied [11] the impact of trade-in subsidies on different models of closed-loop supply chain from three perspectives of the consumer, the scale of the closed-loop supply chain and the enterprises. Fen [12] discussed the problem of channel selection and double recycles channel coordination under the condition of consumer behavior (recycling channel preference and recycling premium) and the two-pole reverse supply chain composed of WEEE recyclers and processors.

To sum up, the existing literature rarely studies the dual-channel recycling closed-loop supply chain by the manufacturer and the retailer recycling. In the literature about dual-channel structure of the manufacturer and the retailer, the transfer price recovered by the manufacturer from the retailer is entirely determined by the manufacturer and does not examine the impact of the retailer on the transfer price and the consumer's environmental awareness, and many researchers considered the consumer's awareness of environmental protection in the dual-channel. It is study the consumer awareness of environmental protection as a quantitative. With the popularization of environmental protection knowledge, consumers' awareness of environmental protection will gradually increase, which will have an impact on the recycling of recycling channels. Therefore, consumers' environmental awareness plays an indispensable role in the decision-making of double-channel closed-loop supply chain. This paper introduces consumer awareness of environmental protection into a closed channel supply chain that is recovered by a manufacturer and retailer. And this article studies the optimal strategy for supply chain members.

This paper studies the optimal strategy of double-channel recycling closed-loop supply chain which considering consumer’s environmental awareness. The innovation of the research is: (1) we consider the influence of the changing consumer's environmental awareness on the optimal pricing strategy of the manufacturer and retailer in the double-channel recycling closed-loop supply chain. (2) We define the transfer price recovered by the manufacturer from the retailer as a variable which is decided by both manufacturer's direct recovery price and the retailer's indirect recovery price. That is, the manufacturer and the retailer jointly decide transfer the price, and then we study the changes of transfer price and the impact of changes on the entire closed-loop supply chain.

2. Model description and assumptions

2.1. Model description

In the closed-loop supply chain of dual-channel recycling, there are two ways to recycle e-waste: one is the direct recovery, that is, Manufacturers directly recycle electronic materials which have a certain value or can also be used for processing from the hands of consumers. We define that the recovery price is p_m. One is the indirect recovery. That is, manufacturers commissioned the retailers recycling electronic waste which also have a certain value or can also be used for processing from the hands of consumers, and we define the retailer's recovery price p_r. The transfer price of the manufacturer recycling from the retailer is defined as p_0. Finally, the recyclable waste is processed and reconstructed by the manufacturer at a recycling cost c, which is distributed to the retailer at the wholesale price ω. And the retailer sells the price to the consumer at the retail price p.The profits of the manufacturer, retailer and the entire channel in the model j ($j = 1,2$) are defined as π_m^j, π_t^j and π^j respectively.

2.2. Basic assumptions

(1) The amount of electronic waste recycling is related to the consumer's environmental awareness, the environmental sustainability of the recycler, the recovery price and the recovery price of the competitor, so the following functions can be used to represent the recovery of the manufacturer and the retailer

$$Q_m = ke_m + b_m p_m - \beta p_r ,$$
$$Q_r = ke_r + b_r p_r - \beta p_m .$$

where Q_m and Q_r represent the recovery of the manufacturer and the retailer, respectively.

b_i ($i = m, r$) represent the price sensitivity of channel i, β represents the cross price sensitivity, $e_i\ (i = m, r)$ indicate the environmental effort of the manufacturer and the retailer. The random variable k represents the level of consumer awareness of environmental protection. And the expected value is $E(k) = u$.

(2) The transfer price p_0 recovered by the manufacturer from the retailer in the indirect recycling channel is greater than the indirect recovery price p_r of the retailer and less than the manufacturer's direct recovery price p_m, so we can get the formula

$$p_0 = p_r + t(p_m - p_r), t \in [0,1].$$

When $t = 0$, the transfer price is equal to the recovery price recovered by the retailer from the consumer. And the retailer is unprofitable. When $t = 1$, the transfer price is equal to the recovery price recovered by the manufacturer from the consumer. Manufacturers will choose indirect recovery completely. That is, all the e-waste on the market by the retailer to recover. So that the situation is considered in the text of $t \in (0,1)$.

(3) The parameters in the model meet the condition of $p_m < \omega - c < p - c$, that is, the manufacturer's direct recovery price p_m is less than the remanufacturing profits $\omega - c$ which is produced by manufacturer remanufacturing the electronic waste of recycling. The manufacturer's recycling is profitable. And the manufacturer's wholesale price must be less than the retailer's price, and the retailer's sales are profitable. $\beta < \min\{b_m, b_r\}$, that is, the recovery rate of other channels has the least impact on the recovery of this channel.

(4) The utilization rate of the recovered e-waste is $\varphi\ (0 < \varphi < 1)$. That is, the recovered e-waste is not used for recycling and remanufacturing completely and it cannot be used for recycling and remanufacturing 100%.

4. Model establishment and solution

Based on the above model description and assumptions, the manufacturer's profit is the income minus costs. Revenue is gained by sold the remanufactured e-waste to the retailer at the wholesale price ω, where the e-waste includes all the waste which can be used for recycling and remanufacturing from the direct recovery channel and the indirect recycling channel. Costs include remanufacturing costs, the cost of directly recycling by the manufacturer, and the transfer costs that manufacturers indirectly recycle from the retailer. The resulting profit function of the manufacturer is

$$\pi_m = \varphi(Q_m + Q_r)(\omega - c) - Q_m p_m - Q_r p_0$$

At the same time, the profit of the retailer is the income minus costs. Revenue is gained by sold the remanufactured e-waste to the consumer at the selling price p and sole the e-waste to the manufacturer at the transfer price p_o. Costs include wholesale costs and the cost of indirectly recovery. The resulting profit function of the retailer is

$$\pi_r = \varphi(Q_m + Q_r)(p - \omega) - Q_r(p_0 - p_r)$$

Suppose $p_0 = p_r + t(p_m - p_r)$, we can get that the profit functions of manufacturer and retailers are written as

$$\pi_m = \varphi(Q_m + Q_r)(\omega - c) - Q_m p_m - Q_r(p_r + t(p_m - p_r)) \tag{1}$$

$$\pi_r = \varphi(Q_m + Q_r)(p - \omega) + Q_r t(p_m - p_r) \tag{2}$$

Consumers sell electronic waste to manufacturers or retailers that can not only get some economic benefits but also get a certain degree of environmental protection. Environmental protection is expressed by the product of environmental awareness and environmental protection. Consumers determine their optimal environmental awareness on the basis of product valuation and environmental effectiveness, which is used θ to represent the consumer's objective valuation of the electronic waste that was held by the consumer. Thus, we can get the consumer utility as follows

$$\begin{aligned} U_c(k) &= E[Q_m(ke_m + p_m - \theta) + Q_r(ke_r + p_r - \theta)] \\ &= (ue_m + b_m p_m - \beta p_r)(ue_m + p_m - \theta) + \\ &\quad (ue_r + b_r p_r - \beta p_m)(ue_r + p_r - \theta). \end{aligned} \tag{3}$$

3.1. Independent decision model

In the independent decision model, the first stage is the consumer to determine the optimal awareness of environmental. And the second stage is manufacturers and retailers to determine the optimal recovery price. The decision order of the manufacturer and the retailer is that the manufacturer first determines the recovery price of the direct recovery channel. And then the retailer determines the recovery price of the indirect recovery channel. Finally, the transfer price is determined by the recovery price of the manufacturer and the retailer.

According to the inverse of the Stackelberg game, we consider the first order partial derivative of the price for the profit of manufacturer and retailer. And we obtained the following formula

$$\frac{\partial \pi_m}{\partial p_m} = \varphi(\omega - c)(b_m - \beta) - ue_m + 2(t\beta - b_m)p_m + (2\beta - t\beta - tb_r)p_r - tue_r \tag{4}$$

$$\frac{\partial \pi_r}{\partial p_r} = \varphi(p - \omega)(b_r - \beta) + t(\beta + b_r)p_m - 2tb_r p_r - tue_r \tag{5}$$

The relationship between the indirect recovery price of the retailer and the direct recovery price of the manufacturer can be obtained as

$$p_r = \frac{\varphi(p-\omega)(b_r-\beta)+t(\beta+b_r)p_m - tue_r}{2tb_r}.$$

From the formula (4) and the formula (5), we obtain the response function of the recovery price of the manufacturer and the retailer. By $\frac{\partial \pi_m}{\partial p_m} = \frac{\partial \pi_r}{\partial p_r} = 0$, we obtained the optimal recovery prices for manufacturers and retailers are written as

$$p_m^{1*} = \frac{2b_r[tue_r + ue_m - \varphi(\omega-c)(b_m-\beta)]}{2\beta b_r(\mathrm{t}+1)-4b_r b_m - tb_r^2 + (2-t)\beta^2} - \frac{(2\beta - t\beta - tb_r)[\varphi(p-\omega)(b_r-\beta)-tue_r]}{2t\beta b_r(\mathrm{t}+1)-tb_r(4b_m+tb_r)+t\beta^2(2-t)} \quad (6)$$

$$p_r^{1*} = \frac{(b_r+\beta)[tue_r+ue_m-\varphi(\omega-c)(b_m-\beta)]}{2\beta b_r(t+1)-4b_r b_m - tb_r{}^2+(2-t)\beta^2} + \frac{2(t\beta-b_m)[\varphi(p-\omega)(b_r-\beta)-tue_r]}{2t\beta b_r(t+1)-tb_r(4b_m+tb_r)+t\beta^2(2-t)} \quad (7)$$

The optimal transfer price is written as

$$p_0^{1*} = \frac{(b_r+\beta)[ue_m-\varphi(\omega-c)(b_m-\beta)+2ue_r(b_m-t\beta)]+(2\beta+t\beta-tb_r-2b_m)[tue_r-\varphi(p-\omega)(b_r-\beta)]}{2\beta b_r(\mathrm{t}+1)-4b_r b_m - tb_r^2+(2-t)\beta^2}$$
$$+\frac{(b_r-\beta)[t^2ue_m - t^2\varphi(\omega-c)(b_m-\beta)+2\varphi(p-\omega)(t\beta-b_m)]}{2t\beta b_r(t+1)-tb_r(4b_m+tb_r)+t\beta^2(2-t)} \quad (8)$$

According to the formula (1), (6), (2) and (7), the manufacturer and the retailer's optimal profit can be obtained as

$$\pi_m^{1*} = \varphi(ue_m + b_m p_m^{1*} - \beta p_r^{1*} + ue_r + b_r p_r^{1*} - \beta p_m^{1*})(\omega - c)$$
$$-(ue_m + b_m p_m^{1*} - \beta p_r^{1*})p_m^{1*} - (ue_r + b_r p_r^{1*} - \beta p_m^{1*})(p_r^{1*} + t(p_m^{1*} - p_r^{1*}))$$

$$\pi_r^{1*} = \varphi(ue_m + b_m p_m^{1*} - \beta p_r^{1*} + ue_r + b_r p_r^{1*} - \beta p_m^{1*})(p-\omega)$$
$$+(ue_r + b_r p_r^{1*} - \beta p_m^{1*})t(p_m^{1*} - p_r^{1*})$$

The optimal profit for the supply chain system is changed as

$$\pi^{1*} = \pi_m^{1*} + \pi_r^{1*}$$

According to formulas (3)(6)(7) and (9), we can obtain

$$\frac{\partial U_c(k)}{\partial u} = 2ue_m^2 + (e_m + b_m e_m - \beta e_r)p_m^{1*} + (e_r + b_r e_r - \beta e_m)p_r^{1*} - (e_m + e_r)\theta \quad (9)$$

And then, let $\frac{\partial U_c(k)}{\partial u} = 0$, the optimal awareness of environmental u_1^* is expressed as

$$u_1^* = \frac{A\theta(e_m+e_r)+t\varphi(\omega-c)(b_m-\beta)[2Bb_r+c(b_r+\beta)]+\varphi(p-\omega)(b_r-\beta)[B(2\beta-t\beta-tb_r)-2C(t\beta-b_m)]}{2Ae_m^2+2Bt^2b_re_r+Ct^2e_r(b_r+\beta)+Cte_m(b_r+\beta)+2Btb_re_m+te_r[B(2\beta-t\beta-tb_r)-2C(t\beta-b_m)]}.$$

where

$$A = 2t^2\beta b_r - 4tb_m b_r + 2t\beta b_r - t^2 b_r^{\ 2} + 2t\beta^2 - t^2\beta,$$

$$B = e_m + b_m e_m - \beta e_r,$$

and

$$C = e_r + b_r e_r - \beta e_m.$$

3.2. Cooperative decision model

In order to realize the maximization of profits, Manufacturers and retailers jointly determine the direct recovery price p_m and the indirect one p_r. Total profit of system π is expressed as

$$\begin{aligned}\pi &= \pi_m + \pi_r \\ &= E\left[\varphi(Q_m + Q_R)(\omega - c) - Q_m p_m + \varphi(Q_m + Q_R)(p - \omega) - Q_r p_r\right]\end{aligned}$$

Based on the above equation, $\frac{\partial \pi}{\partial p_m}$ and $\frac{\partial \pi}{\partial p_r}$ are obtained as follows：

$$\frac{\partial \pi}{\partial p_m} = \varphi(\omega - c)(b_m - \beta) - (ue_m + 2b_m p_m - \beta p_m) + \varphi(p - \omega)(b_m - \beta) + \beta p_r$$

$$\frac{\partial \pi}{\partial p_r} = \varphi(\omega - c)(b_r - \beta) - (ue_r + 2b_r p_r - \beta p_m) + \varphi(p - \omega)(b_r - \beta) + \beta p_m$$

Let $\frac{\partial \pi}{\partial p_m} = 0$ and $\frac{\partial \pi}{\partial p_r} = 0$, the expressions of optimal decision variables for manufacturers and retailers are derived as

$$p_m^{2*} = \frac{u(\beta e_r + b_r e_m)}{2(\beta^2 - b_m b_r)} + \frac{\varphi(p - c)}{2},$$

$$p_r^{2*} = \frac{u(\beta e_m + b_m e_r)}{2(\beta^2 - b_m b_r)} + \frac{\varphi(p - c)}{2}.$$

The optimal internal transfer price p_0^{2*} is expressed as

$$p_0^{2*} = \frac{(1-t)u(\beta e_m + b_m e_r) + tu(\beta e_r + b_r e_m)}{2(\beta^2 - b_m b_r)} + \frac{\varphi(p - c)}{2}$$

The optimal profits for manufacturers and retailers are derived as

$$\begin{aligned}\pi_m^{2*} &= \varphi(ue_m + b_m p_m^{2*} - \beta p_r^{2*} + ue_r + b_r p_r^{2*} - \beta p_m^{2*})(\omega - c) \\ &\quad -(ue_m + b_m p_m^{2*} - \beta p_r^{2*}) p_m^{2*} - (ue_r + b_r p_r^{2*} - \beta p_m^{2*})(p_r^{2*} + t(p_m^{2*} - p_r^{2*}))\end{aligned}$$

$$\pi_r^{2*} = \varphi(ue_m + b_m p_m^{2*} - \beta p_r^{2*} + ue_r + b_r p_r^{2*} - \beta p_m^{2*})(p - \omega)$$
$$+(ue_r + b_r p_r^{2*} - \beta p_m^{2*}) t (p_m^{2*} - p_r^{2*}).$$

The optimal profits of system can be expressed as

$$\pi^{2*} = \varphi(ue_m + b_m p_m^{2*} - \beta p_r^{2*} + ue_r + b_r p_r^{2*} - \beta p_m^{2*})(p - c)$$
$$-(ue_m + b_m p_m^{2*} - \beta p_r^{2*}) p_m^{2*} - (ue_r + b_r p_r^{2*} - \beta p_m^{2*}) p_r^{2*}.$$

Therefore, based on the cooperative decision model, the optimal awareness of environment can get

$$u^{2*} = \frac{(\beta^2 - b_m b_r)\left[2(e_m + e_r)\theta - \varphi(p - c)(B + C)\right]}{2\beta e_m e_r + e_m{}^2(b_r + 3\beta^2 - 3b_m b_r) + e_r{}^2(b_m + b_m b_r - \beta^2)}$$

Property 1. With the increase of awareness of environment, the p_m^{2*} and p_r^{2*} decrease.

Proof: According to $\beta < \min\{b_m, b_r\}$, we can get that $\beta^2 < b_m b_r$, that is, $\beta^2 - b_m b_r < 0$. Then,

$$\frac{\partial p_m^{2*}}{\partial u} = \frac{\beta e_r + b_r e_m}{2(\beta^2 - b_m b_r)} < 0,$$
$$\frac{\partial p_r^{2*}}{\partial u} = \frac{\beta e_m + b_m e_r}{2(\beta^2 - b_m b_r)} < 0.$$

Remark 1. It is noted that consumers will be more proactive in providing waste electronics, which will allow manufacturers and retailers to recycle more of their old electronics with the increase of awareness of environment.

Property 2. The π_2^* increased with the increase of awareness of environment.

Proof: By $p > c$, $\beta^2 - b_m b_r < 0$, and **Property 1**, we can get

$$\frac{\partial \pi_2^*}{\partial u} = \frac{\varphi(p - c)(e_m + e_r)}{2} - \frac{(2 + u)(e_r^2 b_m + e_m^2 b_r) + 2\beta e_m e_r}{2(\beta^2 - b_m b_r)} > 0.$$

Remark 2. It is noted that the market will recycle more electronic waste. Manufacturers produce more electronics and save manufacturing costs, therefore, they increase profits across the supply chain with the increase of awareness of environment.

4. A numerical example

In order to clear more intuitive see consumer environmental awareness on the influence of the optimal strategy, manufacturers transfer price with the change of the manufacturers and retailers price as well as the transfer price changes affect the whole closed-loop supply chain system. In addition, this paper propose a more intuitive comparison of the two models from the size and change of profit, and a numerical analysis of profit changes in manufacturers, retailers and systems is proposed.

4.1. Parametric analysis of independent decision-making model

Let

$e_m = e_r = 1, b_m = 2, b_r = 0.8, \beta = 0.7, \varphi = \theta = 0.8, c = 2, \omega = 4$ and $p = 6$, when t is variable, the corresponding values are shown in Table 1.

Table 1: Variations of each parameter

t	p_m^{1*}	p_r^{1*}	p_0^{1*}	u_1^*	π_m^{1*}	π_r^{1*}	π^{1*}
0.3	0.19	0.122	0.14	3.38	10.08	11.28	21.37
0.32	0.42	0.213	0.28	3.58	9.72	12.59	22.31
0.35	0.81	0.40	0.54	3.89	8.27	14.75	23.02
0.38	1.29	0.65	0.89	4.21	5.38	17.16	22.54
0.4	1.64	0.86	1.17	4.42	2.43	18.92	21.35
0.42	2.03	1.11	1.50	4.63	-1.52	20.80	19.28

According to Table 1, with the increase of t, the optimal environmental protection consciousness and manufacturers direct consumer recycling prices, retailers indirect recover. And manufacturers transfer price increase. With the increase of the manufacturer's transfer price, the manufacturer's cost increases and the profit decreases. In addition, Retailers get a big transfer price from the manufacturer. And the profits of the retailers are increasing. Especially, with the increase of t, manufacturers will not accept such a result when profits are shrinking or even less than zero. Similarly, retailers get smaller transfer price. The unit gains profits will continue to decrease, when t decreases to a certain extent. Retailers profit numerical results will be less than zero. The retailer will not accept the result. Therefore, it needs to be an effective coordination mechanism between manufacturers and retailers. Manufacturers and retailers decide the value of t so that they are willing to accepting the situation. Therefore the supply chain can reach a stable equilibrium state.

4.2. Parameter analysis of cooperative decision model

Let

$$e_m = e_r = 1, b_m = 2, b_r = 0.8, \beta = 0.7, \varphi = 0.8, c = 2, \omega = 4, p = 6,$$

when θ is variable, the corresponding values are shown in Table 2.

Table 2: Variations of each parameter

t	p_m^{2*}	p_r^{2*}	p_0^{2*}	u_2^*	π_m^{2*}	π_r^{2*}	π^{2*}
0.28	1.45	1.33	1.363	0.18	0.518	3.813	4.190
0.3	1.27	0.98	1.077	0.40	1.193	4.104	5.020
0.32	1.08	0.66	0.797	0.62	1.908	4.404	5.931
0.35	0.90	0.33	0.523	0.85	2.658	4.720	6.934
0.38	0.71	0.09	0.269	1.07	3.441	5.051	8.024

Based on Table 2, the increase of awareness of environmental can lead to reduce prices of recycling for manufacturers and retailers. Due to increasing consumer awareness, manufacturers and retailers recycle electronic waste at a lower price. Consumers are willing to accepting a price. And the whole supply chain profit is increased.

4.3. Comparative analysis

Table 1 and Table 2 are respectively based on the analysis of t value changes and consumer awareness. With the change of each parameter, each parameter is variable. From the equilibrium results of independent decision-making model and cooperation decision-making model, we can see that the objective valuation of θ affects the optimal environmental protection consciousness. It does not affect manufacturers, retailers, and profit of the whole supply chain system. Therefore, in order to intuitively compare the difference of the profit between two models, suppose that

$$e_m = e_r = 1, b_m = 2, b_r = 0.8, \beta = 0.7, \varphi = 0.8, c = 2, \omega = 4, p = 6,$$

and the awareness of environment and t are same , we can get that the profit between the two model is obtained in Table 3.

Table 3: The results of comparative analysis

t	u	π_m^{1*}, π_r^{1*}	π_m^{2*}, π_r^{2*}	π^{1*}, π^{2*}	$\pi^{2*} - \pi^{1*} / \pi^{1*} * 100\%$
0.3	3.38	10.08，11.28	14.35，12.3	21.37，26.62	24.6%
0.32	3.58	9.72，12.59	15.43，13.1	22.31，28.51	27.8%
0.35	3.89	8.27，14.75	17.16,，14.4	23.02，31.58	37.2%
0.38	4.21	5.38，17.16	18.98，17.94	22.54，36.92	63.8%
0.4	4.42	2.43，18.92	20.20，19.0	21.35，39.21	83.6%
$\pi_m^{1*} < \pi_m^{2*}, \pi_r^{1*} < \pi_r^{2*}, \pi^{1*} < \pi^{2*}$					

According to Table 3, in the cooperative decision-making, the profits of the manufacturer, the retailer and the total system are greater than that of the independent one. In addition, with the increase of awareness of environment and t, the total profit rate of growth is also increasing. Let t=0.4, u=4.42, the profit of total system is increased by 83.6%. And it shows that the cooperative decision-making is the ideal decision to recycle electronic waste under the awareness of environment.

5. Conclusion

Based on the awareness of environment, this paper studies the double channel of electronic waste recycling of closed-loop supply chain management decision problems. And this article constructs the independent decision-making game model and the cooperative one. In addition, we discuss and the effect of the optimal awareness of environment and the transfer price of the manufacturer on the management of the closed-loop supply chain management in dual channels. Furthermore, we concluded that manufacturers recycling prices p_0 directly affect the profits of manufacturers, retailers and the entire supply chain, but they need for an effective coordination between manufacturers and retailer's mechanism. Manufacturers and retailers determine t value to determine the optimal transfer price so that they are willing to accepting the situation. Hence, the supply chain achieves a steady state. Moreover, the increase of consumer environmental awareness will cause the recycling price reduction of manufacturers and retailers. And the whole supply chain profit increased. Obviously, improving the environmental awareness of consumers not only benefits to double channels recycle mode of manufacturers and retailers, but has a positive effect to the whole supply chain. Finally, through the comparison between the two models, the cooperative decision-making model is an ideal dual-channel recovery closed-loop supply chain management mode under the awareness of environment.

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