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Article

Green Remanufacturer's Mixed Collection Channel Strategy Considering Enterprise's Environmental Responsibility and the Fairness Concern in Reverse Green Supply Chain

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Abstract: In reverse green supply chain, the mixed collection channel strategy of green remanufacturer is analyzed by building a dynamic game model in which we consider that the green remanufacturer undertakes the environmental responsibility and the green collector shows strong fairness concern for the profit. We analyze the impact of the environmental responsibility level of the green remanufacturer, the preference coefficient of the green remanufacturer, the fairness concern coefficient of the green collector, and the coefficient of cross collection price on optimal decision and profit of the green remanufacturer. The result shows that (1) the green remanufacturer can further improve the collection price, so that it makes many more customers participate in the collection activity; (2) the green remanufacturer pays more attention to fulfill the environmental responsibility, which will increase the intensity of collection of the waste green product, and improve the collection price, as the old green product's remanufacturing cost is lower than the production cost of the new product, and it can improve the green remanufacturer's profits; (3) the green remanufacturer's profit in the mixed collection channel is higher than those in online or offline collection channels.

Keywords: fairness concern; environmental responsibility; reverse green supply chain; mixed collection channel strategy; preference coefficient; cross collection price coefficient



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1. Introduction

With the rapid development of industrialization, the environment has been seriously damaged. In recent years, environmental disasters such as the shortage of water resources and the air pollution have occurred frequently. For example, at the beginning of 2013, China suffered from serious smog (Boutesteijn et al. [1]; Talebian et al. [2]). In the same year, the Guangzhou government made an announcement that 44% of the rice was found to have excessive cadmium content in the whole city, which is very harmful (Cohen et al. [3]). Rice grows in contaminated soil, causing cadmium levels in rice to exceed limits. In fact, some villages have evolved into "cancer villages" in China, where cancer cases are much higher than the normal level, and these villages are often located downstream of polluters (Stephen et al. [4]). At the same time, with the rapid development of economy and society, and the continuous improvement of people's living standard, the rapid consumption of energy, which brings a great pressure and threat to control the greenhouse gas emissions, reduces the impact of greenhouse effect, and reduces the environmental damage. Thus, economic development and environmental protection have become a common responsibility of all humans, and green development and environmental protection have become the two major themes of social development. Based on the above analysis, as a response to the awareness of environmental protection from the government and consumers, the enterprises in the

supply chain should pay much more attention to their own degree of green level, and the implementation of green supply chain management has become an inevitable development trend. Green supply chain management is the management activities implemented by firms in order to reduce the impact of economic development on the environment (Swam et al. [5]). Laari et al. [6] can reduce the potential loss risk by using the green supply chain management.

With the increasing attention to the environmental problem, large numbers of enterprises begin to undertake the corresponding environmental responsibility, and continue to pay much attention to the practice of the green supply chain management. For example, in 2012, Xerox has reduced carbon emission by 42%, and has decreased the energy consumption by 31%; Canon has engaged in the green remanufacturing activity by saving energy, reducing waste of resources, and reducing the use of chemicals; Kodak has announced that it would reduce greenhouse gas emissions by 25% through waste product degradation, and saving energy. Through setting up online education course, Walmart advocates the strategic thought of environmental protection, healthy lifestyle, and sustainable economic development. Meanwhile, it emphasizes the low carbon life and reduces the use of plastic bags. Moreover, many customers pay more attention to the green and environmental protection level when they purchase goods. Thus, the manufacturer produces green products and the retailer sells green products so that they can undertake more environmental responsibility. Similarly, in reverse green supply chain, the remanufacturer and the collector should undertake environmental responsibility by recycling waste green products (Feng et al. [7]).

With the improvement of the people's living standard, more people would like to use green products, such as refrigerators, washing machines, and new energy vehicles, etc. At the same time, the upgrade speed of the green environmental protection products is faster and faster, because of the rapid development of science and technology. Some experts point out that in the future, a large number of green environmental protection products will be eliminated, and all these old green products will become a lot of solid wastes. If it cannot be handled well, it will cause serious environmental pollution and a heavy burden on society. Therefore, under the condition of protecting the environment, the implementation of "green collection" should be an effective way. Therefore, similar to the traditional reverse supply chain, adding the recycling and reuse of green products into the green supply chain management, the traditional supply chain becomes the reverse green supply chain. Not only can the remanufacturer collect the old green products through offline channels, but it also can open up the online channels to recycle the green products, and the mixed channels reverse green supply chain will appear.

Traditional economics usually assume that the decision makers are perfectly rational and only consider their own profit maximization. However, this hypothesis cannot explain many phenomenon in our daily life, as in real life, the behavioral studies have found that people tend to show great concern for fairness, that is, fairness concern. For example, taxi companies resist use of the buses by striking, and this is also against their own interests. People will experience dissatisfaction and resentment if they perceive unfairness. Acting under concerns of fairness, people may take actions to punish others at the cost of their own interests when they feel unfairly treated. Fairness concern is incompatible with the traditional utility theory, because it violates the hypothesis of rationality, and many empirical and experimental studies have confirmed the existence of such behavioral tendencies. For example, research in behavioral economics in the past two decades has shown that "there is a significant incidence of cases in which firms, like individuals, are motivated by fairness concerns" in business relationships, including channel relationships. Studies in economics and marketing have long documented cases where fairness plays an important role in developing and maintaining channel relationships (Okun [8], Frazier [9], Kaufmann and Stern [10], Anderson and Weitz [11], Corsten and Kumar [12]). For example, through a large scale survey of car dealerships in the United States and Netherlands, Kumar et al. [13] convincingly show that fairness is a significant determinant of the quality

of channel relationships. Indeed, some practitioners go as far as to say that maintaining fairness in a distribution channel “should be the supplier’s first concern”. Therefore, fairness concerns are a factor that analytical modelers in marketing may not want to ignore as they strive to develop good descriptive models of channel coordination.

Thus, the paper attempts to answer the following research questions:

- (1) In reverse green supply chain, the green collector exists the fairness concern when the green remanufacturer undertakes the corresponding environmental responsibility. Would the green remanufacturer like to undertake the environmental responsibility or not?
- (2) Would the green remanufacturer choose a single collection channel or dual collection channel to collect green products under the condition of undertaking environmental responsibility?

The remainder of this paper is organized as follows. Section 2 provides a literature review. Section 3 presents the problem and the relevant assumptions. Section 4 explores the remanufacturer’s collection channel. Section 5 makes comparisons of the different collection channels. Section 6 extends the result by using numerical analysis. This study ends with some concluding remarks in Section 7.

2. Literature Review

At present, the literature related to this paper is mainly concentrated in two aspects: (1) The collection channel strategy and coordination in reverse supply chain; (2) the collection channel strategy and coordination in reverse supply chain under fairness concern.

2.1. The Collection Channel Strategy and Coordination in Reverse Supply Chain

In recent years, a new round of industrial revolutions has made it so the collection of resources has become one of the most important problems which a large number of countries and enterprises focus on. The collection and reuse of resources has become the key problem for enterprises to improve the economic benefit. The reverse supply chain is an important way to realize the reuse of resources, and it can bring certain economic benefit for the enterprise. For example, Xerox has implemented the regeneration strategy for 20 years, and has saved the total manufacturing cost by more than 50%. Dupont collects and reuses the raw materials used for remanufacturing activities.

Under this background, the collection channel strategy in a reverse supply chain has received extensive attention from scholars. For example, Savaskan et al. [14] analyzed the optimal collection channel strategy problem in closed loop supply chain using game theory. Mukhopadhyay et al. [15] analyzed the relationship between the best buyback strategy and product design strategy. Guide [16] studied the commodity value attenuation problem in closed loop supply chain, and pointed out that the collection effect is better in a decentralized decision making process when the available commodity value is higher. Webster et al. [17] studied the manufacturer and remanufacturers’ decision making problem when the third party collected the waste products. Hong and Yeh [18] compared the difference between the third party collection model and the retailer collection model in a WEEE closed loop supply chain. Based on Savaskan’s work, Atasu et al. [19] analyzed the manufacturers’ collection channel selection strategy problem under the condition of the scale economy. Based on Atasu’s work, Chuang et al. [20] studied the high technology product manufacturers’ recycling channel selection strategy. The above studies have discussed the collection channel strategy problem in a traditional reverse supply chain. However, they didn’t analyze the collection channel’s coordination problem in a reverse supply chain.

After that, large numbers of studies begin to pay much attention to the collection channel’s coordination problem in reverse supply chains. For example, Giovanni [21] studied the manufacturers’ different collection channels, and pointed out the condition under which the manufacturer could delegate the collection business to the retailer or the third party. He and Xu [22] introduced some typical WEEE collection technologies, and

a comprehensive WEEE collection system was proposed. Ayvaz et al. [23] proposed a general reverse logistic network design model under the condition of quality uncertainty of WEEE. Giovanni [24] built the incentive strategy model when the manufacturer and the retailer recycled the waste product. Considering the dual channel competitive, Yi et al. [25] discussed the optimal pricing and recovery decision for the members in a closed loop supply chain. Polat et al. [26] studied the WEEE collection planning problem in multiple periods, so that they could determine the optimal collection strategy.

To sum up, the above studies mainly discuss the collection channel strategy, the relevant factors, and the optimal decision problem in reverse supply chains. However, all the studies assume that the relevant stakeholders are “rational people” who only focus on their own profit maximization. None of the above studies takes into account the firms’ fairness concern in reverse supply chains. Moreover, none of them analyze the impact of fairness concern on the collection channel strategy in reverse supply chains.

2.2. The Collection Channel Strategy and Coordination in Reverse Supply Chain under Fairness Concern

This part mainly summarizes the existing literature from the perspective of the impact of fairness concern on the collection channel selection strategy and coordination in reverse supply chains. Cui [27] was the first to introduce fairness concern into supply chain management, and studied the coordination of dual recycling channels. Based on Cui’s work, Caliskan [28] extended his findings to other functional forms, and pointed out that the exponential function is more likely to achieve supply chain coordination in the case of retailer’s fairness concern. Mathies et al. [29] studied how consumers choose collection channels under the influence of fairness concern behavior. Katok et al. [30] suggested that the fairness concern of members seriously affected the efficiency of contract on supply chain coordination. Han et al. [31] studied the optimal pricing and coordination in closed loop supply chains considering the fairness concern of decision members. Under four different collection channel structure models, Ma et al. [32] studied the closed loop supply chain coordination considering the retailer’s fairness concern. Genc et al. [33] studied the consumer’s return behavior and proposed the optimal rebate mechanism under the condition of fairness concern. Hong et al. [18] built a two periods closed loop supply chain model consisting of a manufacturer and remanufacturer under the condition of fairness concern, and analyzed the impact of fixed fees on the decision making members in closed loop supply chains. Giovanni [34] analyzed the impact of joint incentive contract on the closed loop supply chain under the condition of fairness concern. Considering the competition and cooperation between different members, Wu et al. [35] studied the equilibrium decision making and profit of each member in closed loop supply chains, and proposed two kinds of cooperation mechanisms under the condition of fairness concern.

2.3. The Collection Channel Strategy and Operations Management in Green Supply Chain

With the increasingly serious environmental problems, large numbers of scholars have begun to pay much more attention to green supply chain management (GSCM). Some literature discusses the operations management in GSCM by using the theoretical method. For example, Zhang and Li [36] compared and analyzed the optimal decision making of the manufacturer and retailer in the green supply chain, and then studied the effect of green efficiency on GSCM. Dey et al. [37] discussed the optimal pricing and product green decision in a two period green supply chain, and found that the retailer’s purchasing decision is a key factor in the Manufacturer Stackelberg vertical game. Yang et al. [38] studied the impact of manufacturer’s green investment on product quality levels and the optimal pricing decisions of the manufacturer and retailer in the supply chain, and found that the manufacturer is more willing to invest green cost with lower green sensitivity. Yan et al. [39] analyzed the impact of wholesale price contracts, cost sharing contracts, and two part contracts on green product demand, supply chain member profits, and channel profits in a retailer-led bilateral monopoly green supply chain. Khorshidvand et al. [40] explored the coordinated decisions regarding a multi-level multi-channel supply chain

considering the price of sale channels, the advertisement level, and the green policy of the products. Another general issue worth mentioning is the empirical research in the green supply chain management with the use of actual data. For example, Qu et al. [41] discussed the three stage multi-criteria decision making (MCDM) method considering the interval valued best worst method (BWM) and social networks including the three main modules. Qu et al. [42] analyzed the uncertainty in the prediction and management of CO₂ emissions by using the robust minimum entropy approach. Gong et al. [43] used the belief degree and uncertainty distribution to fit individual preferences, and five scenarios of uncertain chance constrained minimum cost consensus models were further discussed. Bhatia et al. [44] collected and reviewed the research on green supply chains between 2001 and 2019.

In a word, large numbers of scholars have discussed the collection channel strategy, the optimal pricing, and the optimal decision making in reverse supply chain under fairness concern. Some literature has analyzed the operations management in the green supply chain management. However, the above literature does not analyze the impact of the firms' environmental responsibility on the collection channels strategy in reverse supply chains. Moreover, no scholar discusses the mixed collection channel strategy in reverse green supply chains under the condition of fairness concern and environmental responsibility. To fill this gap, this is the first time for the dual collection channel reverse green supply chain as a research object. Moreover, we introduce the fairness concern and environmental responsibility into the reverse green supply chain, and analyze the green remanufacturer's mixed collection channel strategy problem by using game model when the green remanufacturer undertakes the environmental responsibility and the green collector shows strong fairness concern for the profit.

3. Research Methods

3.1. Problem Description and Symbol Instruction

In a symmetric information situation, we build a two level reverse green supply chain which considers one green remanufacturer and one green collector. The green remanufacturer can collect waste green product through three collection channels (online collection channel, offline collection channel, and the mixed collection channel), see the theoretical game model in Figure 1, and the relevant parameters and decision variables are listed in Table 1.

- (1) In the offline collection channel: The green collector can collect waste green products from consumers at the collection price R_1 , and the green remanufacturer collects the waste green products from the green collector at the collection price w ;
- (2) In the online collection channel: The green remanufacturer can collect waste green products from the consumer at the collection price R_2 ;
- (3) In the mixed collection channel: On the one hand, in the offline collection channel, the green remanufacturer collects waste green products from the green collector at the collection price w , and the green collector collects waste green product from the consumer at the collection price R_1 ; on the other hand, the green remanufacturer can collect waste green products from consumers at the collection price R_2 .

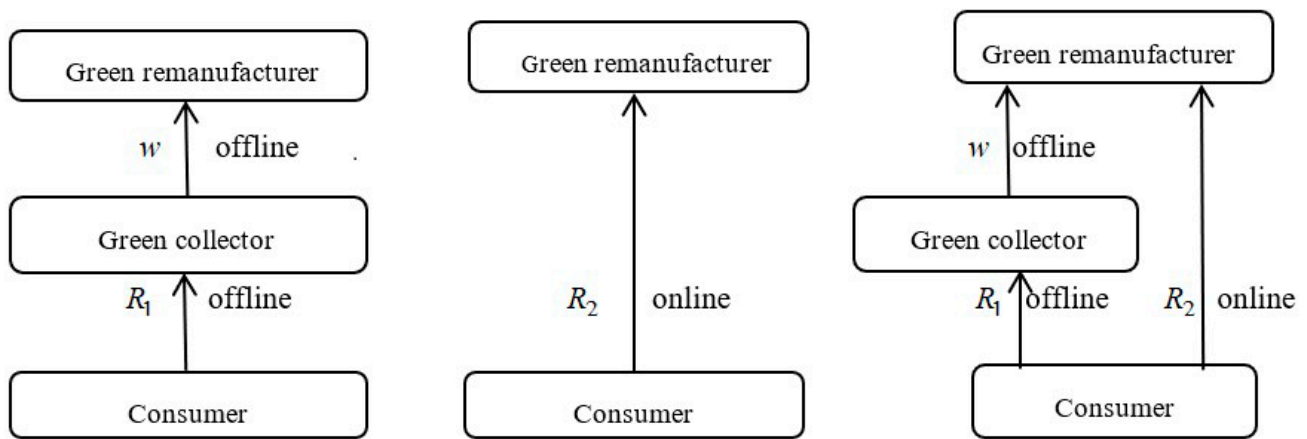


Figure 1. Three collection channels of the green remanufacturer's.

Table 1. The relevant parameters and decision variables.

Variables	Symbols	Concept
Decision variables	w^*	The collection price when the green remanufacturer collects the waste product from the green collector in an offline channel in Section 4.1
	w^{***}	The collection price when the green remanufacturer collects the waste product from the green collector in an mixed channel in Section 4.3
	R_1^*	The collection price when the green collector collects the waste product from the customer in an offline channel in Section 4.1
	R_1^{***}	The collection price when the green collector collects the waste product from the customer in an mixed channel in Section 4.3
	R_2^{**}	The collection price when the green remanufacturer collects the waste product from the customer in an online channel in Section 4.2
	R_2^{***}	The collection price when the green remanufacturer collects the waste product from the customer in an mixed channel in Section 4.3
Relevant parameters	q_1	The collection quantity in an offline channel
	η_m	The green remanufacturer's environmental responsibility level
	c_m	The unit cost of new products which are produced by raw material
	c_r	The unit remanufacturing cost of a new product which is produced by waste green product
	μ	The green remanufacturer's remanufacturing utilization of waste green products
	g	The unit remanufacturing cost when the waste green product's remanufacturing utilization is 1
	q_2	The collection quantity in an online channel
	ϕ	The market share in an offline channel
	a	The customer's environmental protection consciousness
	θ	The cross collection price impact coefficient, and $\theta > 0$
	φ	The green remanufacturer's preference coefficient of waste green products, and $\varphi > 0$
	τ	The degree level of the waste green product
	k_m	The green remanufacturer's environmental responsibility efficiency
	p	The market selling price of the green remanufacturing product
λ	The green collector's fairness concern coefficient	
π_m^*	The green remanufacturer's profit in an offline channel in Section 4.1	
π_m^{**}	The green remanufacturer's profit in an online channel in Section 4.2	
π_m^{***}	The green remanufacturer's profit in an mixed channel in Section 4.3	

3.2. The Assumptions

In order to better understand the game model, the relevant assumptions are as follows:

- (1) In offline collection channels, the collection network of green recyclers has been built, the green collector can collect the waste green products using these recycling networks. Thus, the green collector does not consider the fixed collection investment. At the same time, in order to simplify the calculation, we do not consider the green remanufacturer or the green collector's collection cost;
- (2) There is no difference between the quality of the new product and the remanufactured product that is produced by the green remanufacturer;
- (3) This paper mainly discusses the mixed collection channel strategy of green remanufacturers in reverse green supply chains. Therefore, it is assumed that the selling price of the remanufactured product is constant.

- (4) The green remanufacturer gives different collection prices based on the degree of waste green products, thus it is assumed that the relationship between the remanufacturer’s fixed collection cost I_m and the degree level of waste green products τ can be expressed as $I_m = \beta_m \tau^2$, where, β_m is the green remanufacturer’s fixed cost coefficient.
- (5) The green product can be produced by raw materials, or it can be remanufactured by the waste green products, and we have $c_r = c_m - \mu(c_m - g)$, the green products produced in both cases will be sold at the same price in the market.

3.3. The Methods

In the paper, the green remanufacturer is the leader, the green collector is the follower. The game model will be built between the green remanufacturer and the green collector. We solve the game model by using the backward induction method.

4. The Remanufacturer’s Mixed Recycling Channels Game Model

4.1. The Offline Collection Channel Game Model

In this case, the green remanufacturer is the leader and should consider the environmental responsibility, the green collector is the follower and have fairness concerns about profit. The collection quantity of the waste green product is $q_1 = a + R_1 + \varphi\tau + k_m\eta_m$.

The profit function of green remanufacturer is:

$$\pi_m = (p - w + c_m - c_r)q_1 \tag{1}$$

The profit function of green collector is:

$$\pi_r = (w - R_1)q_1 \tag{2}$$

The overall profit of reverse green supply chain is:

$$\pi_t = (p + c_m - c_r - R_1)q_1 \tag{3}$$

The fairness concern utility of the collector is:

$$u_t = \pi_r - \lambda\pi_t \tag{4}$$

Proposition 1. *In the decision making model of the offline collection channel, when the green remanufacturer considers the environmental responsibility and the green collector has fairness concerns about profit. The green remanufacturer’s profit π_m is the concave function with w , the fairness concern utility of the collector u_r is the concave function with R_1 , and the optimal collection price w^* and R_1^* can be expressed as:*

$$w^* = \frac{(p + c_m - c_r) + a + \lambda(c_m - c_r + p) + (\lambda + 1)[\varphi\tau + k_m\eta_m]}{2(1 - \lambda)}$$

$$R_1^* = \frac{(p + c_m - c_r) + (1 + \lambda)[\varphi\tau + k_m\eta_m] - \lambda(c_m - c_r + p) + a(1 - \lambda)}{2(1 - \lambda)}$$

Proof. The sequence of the offline collection channel is as follows: (I) Based on the reaction of the green collector, the green remanufacturer should decide the collection price w ; (II) based on the green remanufacturer’s collection price w , the green recycler decides the collection price R_1 . According to Equations (1) and (4), the first derivative of the green collector’s fairness concern utility u_r with R_1 using the backward induction method is:

$$\frac{\partial u_r}{\partial R_1} = w - R_1 - \lambda(c_m - c_r + p - R_1) + (\lambda - 1)(k_m\eta_m + R_1 + a + \varphi\tau)$$

The optimal reaction function of the collection price R_1 is:

$$R_1 = \frac{w - \lambda(c_m - c_r + p) + (\lambda - 1)(k_m\eta_m + a + \varphi\tau)}{2(1 - \lambda)}$$

The first derivation of the remanufacturer's profit π_m with w is:

$$\frac{\partial \pi_m}{\partial w} = - \left(a + \frac{w - \lambda(c_m - c_r + p) + (\lambda - 1)(k_m\eta_m + a + \varphi\tau)}{2(1 - \lambda)} + \varphi\tau + k_m\eta_m \right) + \frac{(p - w + c_m - c_r)}{2(1 - \lambda)}$$

The green remanufacturer's optimal collection price is:

$$w^* = \frac{(p + c_m - c_r) + a + \lambda(c_m - c_r + p) + (\lambda + 1)[\varphi\tau + k_m\eta_m]}{2(1 - \lambda)}$$

Then, the green collector's optimal collection price is:

$$R_1^* = \frac{(p + c_m - c_r) + (1 + \lambda)[\varphi\tau + k_m\eta_m] - \lambda(c_m - c_r + p) + a(1 - \lambda)}{2(1 - \lambda)}$$

□

4.2. The Online Collection Channel Game Model

In this case, the green remanufacturer is the leader and should consider the environmental responsibility, the collector is the follower and have fairness concerns about profit. The collection quantity of the waste green product in the online collection channel is $q_2 = a + R_2 + \varphi\tau + k_m\eta_m$. The profit function of green remanufacturer is:

$$\pi_m = (p - R_2 + c_m - c_r)q_2 \tag{5}$$

Proposition 2. *In the decision making model of the online collection channel, when the green remanufacturer considers the environmental responsibility, the remanufacturer's profit π_m is the concave function with R_2 , and the optimal collection price R_2^* can be expressed:*

$$R_2^* = \frac{p + c_m - c_r + a + \varphi\tau + k_m\eta_m}{2(1 - \lambda)}$$

Proof. In online collection channel, the green remanufacturer decides the recycling price R_2 , the first derivation of the remanufacturer's profit π_m with R_2 is:

$$\frac{\partial \pi_m}{\partial R_2} = -(a + R_2 + \varphi\tau + k_m\eta_m) + (p - R_2 + c_m - c_r)$$

The green remanufacturer's optimal collection price is:

$$R_2^{**} = \frac{p + c_m - c_r + \varphi\tau + k_m\eta_m}{2(1 - \lambda)}$$

□

4.3. The Mixed Collection Channel Game Model

In this case, the green remanufacturer is the leader and should consider the environmental responsibility, the collector is the follower and should have fairness concerns about profit. The collection quantities of the waste green product in the online collection channel and in the offline collection channel are $q_1 = a + R_1 - \theta R_2 + \varphi\tau + k_m\eta_m$ and $q_2 = a + R_2 - \theta R_1 + \varphi\tau + k_m\eta_m$.

The profit function of green remanufacturer is:

$$\pi_m = (p - w + c_m - c_r)q_1 + (p - R_2 + c_m - c_r)q_2 \tag{6}$$

The profit function of green collector is:

$$\pi_r = (w - R_1)q_1 \tag{7}$$

The overall profit of reverse green supply chain is:

$$\pi_t = (p + c_m - c_r - R_1)q_1 + (p - R_2 + c_m - c_r)q_2 \tag{8}$$

The fairness concern utility of the green collector is:

$$u_t = \pi_r - \lambda\pi_t \tag{9}$$

Proposition 3. *In the decision making model of the mixed collection channel, when the green remanufacturer considers the environmental responsibility and the green collector has fairness concerns about profit. The green remanufacturer’s profit π_m is the concave function with w and R_2 , the fairness concern utility of the green collector u_r is the concave function with R_1 , and the optimal collection price w^{***} , R_1^{***} , and R_2^{***} can be expressed as:*

$$w^{***} = \frac{a + (\theta - 1)(c_m - c_r + p) + \varphi\tau + k_m\eta_m}{2(1 - \lambda)}$$

$$R_1^{***} = \frac{2a(\lambda - 1) + (1 - 2\theta)(c_m - c_r + p) + \lambda k_m\eta_m - \lambda(c_m - c_r + p)}{2(1 - \lambda)}$$

$$R_2^{***} = \frac{a - a\lambda + (\theta - 1 - \lambda)(c_m - c_r + p) + \varphi\tau + k_m\eta_m}{2(1 - \lambda)}$$

Proof. The sequence of the mixed collection channel is as follows: (I) Based on the reaction of green collector, the green remanufacturer should decide the recycling price w and R_2 ; (II) based on the green remanufacturer’s collection price, the green recycler decide the collection price R_1 . The first derivative of the green collector’s fairness concern utility u_r with R_1 using the backward induction method is:

$$\frac{\partial u_r}{\partial R_1} = w - 2R_1 - a - \varphi\tau + \theta R_2 - k_m\eta_m + \lambda(a - c_m + c_r - p + 2R_1 + \varphi\tau - \theta R_2 + k_m\eta_m + \theta(c_m - c_r - R_2 + p))$$

The optimal reaction function of the collection price R_1 is:

$$R_1 = \frac{w - a - \varphi\tau + \theta R_2 - k_m\eta_m + \lambda(a - c_m + c_r - p + \varphi\tau - \theta R_2 + k_m\eta_m + \theta(c_m - c_r - R_2 + p))}{2(1 - \lambda)}$$

The first derivation of the remanufacturer’s profit π_m with w and R_2 is:

$$\frac{\partial \pi_m}{\partial w} = (p - w + c_m - c_r) \left(a + \frac{w - a - \varphi\tau + \theta R_2 - k_m\eta_m + \lambda(a - c_m + c_r - p + \varphi\tau - \theta R_2 + k_m\eta_m + \theta(c_m - c_r - R_2 + p))}{2(1 - \lambda)} - \theta R_2 + \varphi\tau + k_m\eta_m \right) + (p - R_2 + c_m - c_r) \left(a + R_2 - \theta \left(\frac{w - a - \varphi\tau + \theta R_2 - k_m\eta_m + \lambda(a - c_m + c_r - p + \varphi\tau - \theta R_2 + k_m\eta_m + \theta(c_m - c_r - R_2 + p))}{2(1 - \lambda)} \right) + \varphi\tau + k_m\eta_m \right)$$

$$\frac{\partial \pi_m}{\partial R_2} = (p - w + c_m - c_r) \left(a + \frac{w - a - \varphi\tau + \theta R_2 - k_m\eta_m + \lambda(a - c_m + c_r - p + \varphi\tau - \theta R_2 + k_m\eta_m + \theta(c_m - c_r - R_2 + p))}{2(1 - \lambda)} - \theta R_2 + \varphi\tau + k_m\eta_m \right) + (p - R_2 + c_m - c_r) \left(a + R_2 - \theta \left(\frac{w - a - \varphi\tau + \theta R_2 - k_m\eta_m + \lambda(a - c_m + c_r - p + \varphi\tau - \theta R_2 + k_m\eta_m + \theta(c_m - c_r - R_2 + p))}{2(1 - \lambda)} \right) + \varphi\tau + k_m\eta_m \right)$$

The green remanufacturer’s optimal collection price is:

$$w^{***} = \frac{a + (\theta - 1)(c_m - c_r + p) + \varphi\tau + k_m\eta_m}{2(1 - \lambda)}$$

$$R_2^{***} = \frac{a - a\lambda + (\theta - 1 - \lambda)(c_m - c_r + p) + \varphi\tau + k_m\eta_m}{2(1 - \lambda)}$$

Then, the green collector’s optimal collection price is:

$$R_1^{***} = \frac{2a(\lambda - 1) + (2\theta - 1)(c_m - c_r + p) + \lambda\varphi\tau + \lambda k_m\eta_m - \lambda(c_m - c_r + p)}{2(1 - \lambda)}$$

□

5. Result Analysis

In this section, we analyze the equilibrium results under three kinds of collection channels, and discuss the green remanufacturer’s optimal collection channel strategy. Then, we analyze the impact of fairness concern behavior and the different collection channels’ market share on the green remanufacturer’s collection channel strategy, and provide the theoretical guidance for the remanufacturer’s collection channel strategy.

Corollary 1. Comparing with the optimal collection price between the offline collection channel and the mixed collection channel, we have $w^{***} < w^*$, $R_1^{***} < R_1^*$; comparing with the optimal collection price between the online recycling channel and the mixed collection channel, we have $R_2^{***} < R_2^*$.

Proof. $w^{***} - w^* = \frac{-(2-\theta+\lambda)(c_m-c_r+p)-\lambda(\varphi\tau+k_m\eta_m)}{2(1-\lambda)} < 0$, thus we have $w^{***} < w^*$;
 $R_1^{***} - R_1^* = \frac{a(\lambda-1)-2\theta(c_m-c_r+p)-(\varphi\tau+k_m\eta_m)}{2(1-\lambda)} < 0$, thus we have $R_1^{***} < R_1^*$;
 $R_2^{***} - R_2^* = \frac{-(2-\theta+\lambda)(c_m-c_r+p)-a\lambda}{2(1-\lambda)} < 0$, thus we have $R_2^{***} < R_2^*$. □

Corollary 2. Suggests that the collection price in a mixed collection channel is lower than that in an online or offline collection channel. This suggests that the remanufacturer can improve the collection quantity of the waste green product using mixed collection channel, and it can help the remanufacturer to improve the environmental responsibility. However, Hong et al. [34] and Dan et al. [44] have pointed out that the remanufacturer could collect the WEEE using the online collection channel. On the other hand, we can find that the collection price in online or offline collections channel is higher than that in mixed collection channels. This can show that the remanufacturer should pay for more money to collect the waste green products, and this will reduce the profits of the remanufacturer to some extent.

Corollary 3. With the increasing of the green remanufacturer’s environmental responsibility η_m , the collection price w^* in offline collection channel, the collection price R_2^{**} in online collection channel, and the collection price w^{***} and R_2^{***} in mixed collection channel are increasing.

Proof. The first derivatives are:

$$\frac{\partial w^*}{\partial \eta_m} = \frac{k_m(\lambda + 1)}{2(1 - \lambda)} > 0; \frac{\partial R_2^{**}}{\partial \eta_m} = \frac{k_m}{2(1 - \lambda)} > 0; \frac{\partial w^{***}}{\partial \eta_m} = \frac{k_m}{2(1 - \lambda)} > 0; \frac{\partial R_2^{***}}{\partial \eta_m} = \frac{k_m}{2(1 - \lambda)} > 0$$

□

Corollary 4. This suggests that with the improving of the green remanufacturer’s environmental responsibility, the collection price in three collection channel is increasing. This implies that the green remanufacturer can increase the collection quantity when the green remanufacturer under environmental responsibility. From the above analysis, it has a positive relationship between the green remanufacturer’s environmental responsibility and the collection price under three kinds of

collection channel strategies. This result is similar to that of Polat et al. [26], who pointed out that in order to collect more waste electronic and electrical products (WEEE), the remanufacturer could undertake more environmental responsibility.

Corollary 5. With the increasing of the cross collection coefficient θ , the collection price w^{***} and R_2^{***} in mixed collection channels are increasing, and the collection price of the green recycler R_1^{***} is decreasing.

Proof. The first derivatives are:

$$\frac{\partial w^{***}}{\partial \theta} = \frac{c_m - c_r + p}{2(1 - \lambda)} > 0; \frac{\partial R_1^{***}}{\partial \theta} = \frac{-(c_m - c_r + p)}{(1 - \lambda)} < 0; \frac{\partial R_2^{***}}{\partial \theta} = \frac{c_m - c_r + p}{2(1 - \lambda)} > 0$$

□

Corollary 6. This suggests that with the increasing of the cross collection coefficient, the green remanufacturer’s collection prices are also increasing. However, the green recycler’s collection price is reduced in the mixed collection channel. As is known to us, the cross collection coefficient represents the degree of interaction between the online collection channel and the offline collection channel. The green remanufacturer should set the appropriate collection price between these two collection channels, so that it can reduce the impact of channel conflicts on the profit.

Corollary 7. The green remanufacturer’s preference coefficient for the waste green product φ has the positive relationship with the collection price w^* , w^{***} , R_1^{**} , R_1^{***} , R_2^{**} , and R_2^{***} in three kinds of collection channels.

Proof. The first derivatives are:

$$\begin{aligned} \frac{\partial w^*}{\partial \varphi} &= \frac{\tau(\lambda + 1)}{2(1 - \lambda)} > 0; \frac{\partial R_1^*}{\partial \varphi} = \frac{\tau(1 + \lambda)}{2(1 - \lambda)} > 0; \frac{\partial R_2^{**}}{\partial \varphi} = \frac{\tau}{2(1 - \lambda)} > 0; \frac{\partial w^{***}}{\partial \varphi} = \frac{\tau}{2(1 - \lambda)} > 0; \\ \frac{\partial R_1^{***}}{\partial \varphi} &= \frac{\lambda\tau}{2(1 - \lambda)} > 0; \\ \frac{\partial R_2^{***}}{\partial \varphi} &= \frac{\tau}{2(1 - \lambda)} > 0. \end{aligned}$$

□

Corollary 8. This suggests that with the increasing of the green remanufacturer’s preference coefficient for the waste green product, the collection price in three collection channels are increasing. This is because the green remanufacturer’s preference coefficient is increasing, and the green remanufacturer can collect much more waste green product by improving the collection price, so that it can improve the status in the heart of consumers, establish the brand image of the enterprise, and better fulfill the environmental responsibility.

Corollary 9. With the increasing of the green recycler’s coefficient of fairness concern λ , the collection price w^* , w^{***} , R_1^{**} , R_1^{***} , R_2^{**} , and R_2^{***} in three collection channels are increasing.

Proof. The first derivatives are:

$$\begin{aligned} \frac{\partial w^*}{\partial \lambda} &= \frac{3(c_m - c_r + p) + 2(\varphi\tau + k_m\eta_m)(1 - \lambda) + 2a + 2\lambda(c_m - c_r + p) + 2(\lambda + 1)(\varphi\tau + k_m\eta_m)}{4(1 - \lambda)^2} > 0; \frac{\partial R_1^*}{\partial \lambda} = \frac{\varphi\tau + k_m\eta_m}{(1 - \lambda)^2} > 0; \\ \frac{\partial R_2^{**}}{\partial \lambda} &= \frac{(p + c_m - c_r + a + \varphi\tau + k_m\eta_m)}{2(1 - \lambda)^2} > 0; \frac{\partial w^{***}}{\partial \lambda} = \frac{a + (\theta - 1)(c_m - c_r + p) + \varphi\tau + k_m\eta_m}{2(1 - \lambda)^2} > 0; \\ \frac{\partial R_1^{***}}{\partial \lambda} &= \frac{\varphi\tau + k_m\eta_m + 2\theta(c_m - c_r + p)}{2(1 - \lambda)^2} > 0; \end{aligned}$$

$$\frac{\partial R_2^{***}}{\partial \lambda} = \frac{2a(1 - \lambda) + \varphi\tau(2 - \lambda) + a\lambda(1 - \lambda) + (\theta - 1 - \lambda)(c_m - c_r + p)(2 - \lambda) + k_m\eta_m(2 - \lambda)}{2(1 - \lambda)^2} > 0.$$

□

Corollary 10. *This suggests that on the one hand, the green remanufacturer should make its own profit maximization, and pay much more attention to the degree of the green recycler’s fairness concern for profit. On the other hand, the green remanufacturer should improve the collection price of the waste green products, collect more waste green products, and undertake more environmental responsibility.*

6. Numerical Analysis and Result Discussion

6.1. Numerical Analysis

In this section, we should test the validity of model by using numerical analysis, referring to Zhou et al. [45] and Dan et al. [46] and combined with the practices. From Proposition 1, Proposition 2, and the Proposition 3, we can obtain that in order to make the profit of the green remanufacturer, and the green recycler is concave function. As a result, the profit of the green remanufacturer and the recyclers have a maximum value. The ranges for each parameter are $c_m > 0, c_r > 0, a > 0, k_m > 0, \eta_m > 0, \lambda \in (0, 1), \varphi \in (0, 1), \tau \in (0, 1), \theta \in (0, 1)$. Based on above analysis, we assume that $c_m = 10, c_r = 6, a = 100, \lambda = 0.9, \varphi = 0.6, \tau = 0.5, k_m = 3, \eta_m = 5, \theta = 0.5$, we can get the following Figures 2–6 by using the Matlab software.

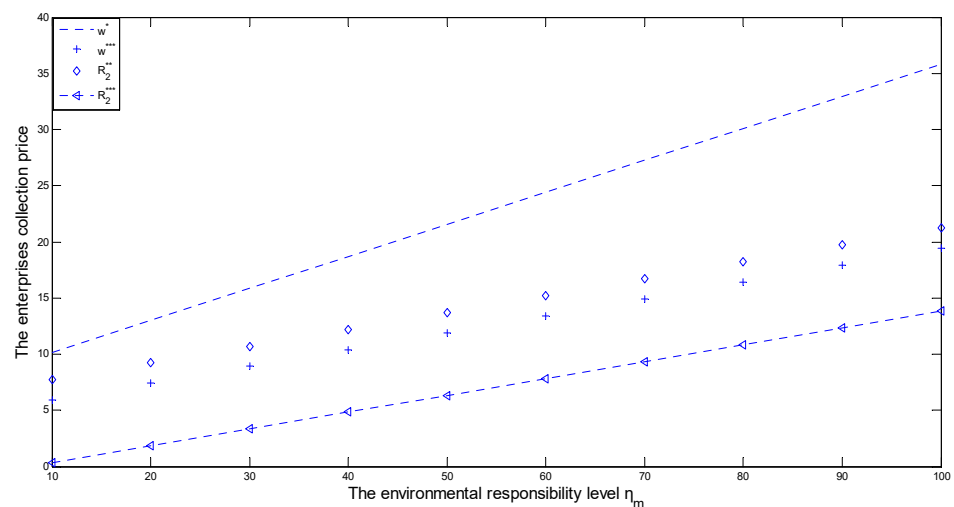


Figure 2. The impact of environmental responsibility on the collection price w^* R_2^{**} w^{***} and R_2^{***} .

Figure 2 illustrates that it has the positive relationship between the green remanufacturer’s environment responsibility and the collection price in three collection channels. Faced with the reality of the environmental pollution and the ecological destruction, and the pressure from the government, the enterprise must further improve the awareness of the environmental responsibility and increase the collection of waste green product. In this situation, the green remanufacturer will further improve the collection price so that it can attract customers to participate in the collection activities. At the same time, the recycling price in mixed collection channel is lower than that in online or in offline collection channels. This is because the green remanufacturer gives lower collection price to the customers under the mixed collection channel, the green remanufacturer pay for the lower cost. Finally, the green remanufacturer gets a relatively higher profit, which is more favorable to the green remanufacturer.

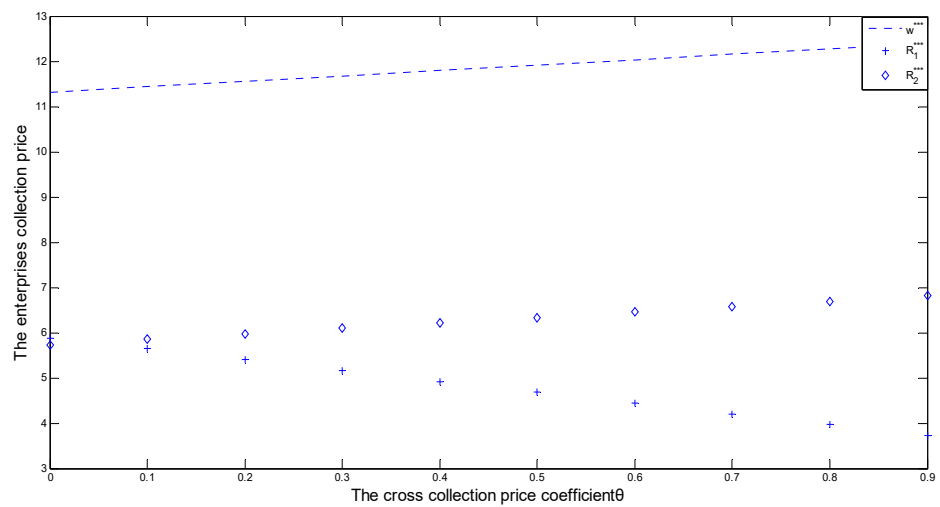


Figure 3. The impact of the cross collection price coefficient θ on the collection price w^{***} , R_2^{***} and R_1^{***} .

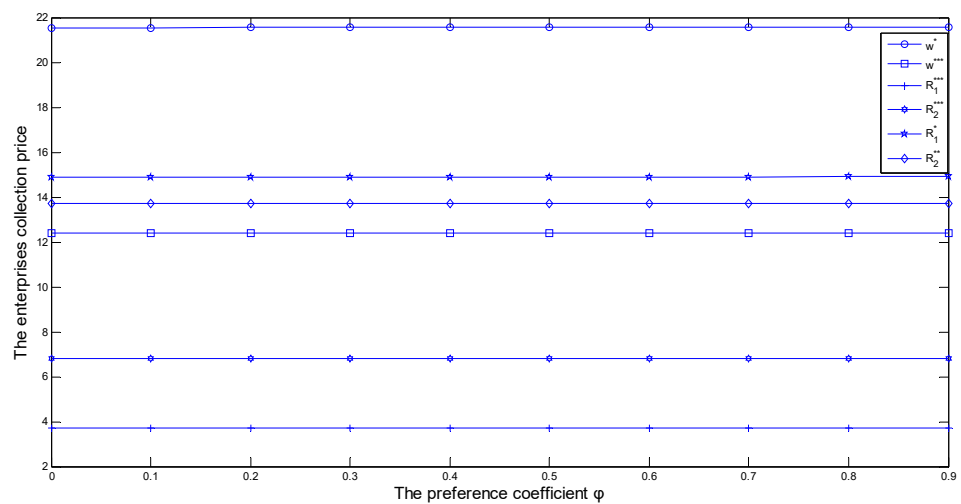


Figure 4. The impact of preference coefficient ϕ on the collection price w^* , w^{***} , R_1^* , R_1^{***} , R_2^{**} and R_2^{***} .

Figure 3 shows that with the increasing of the cross collection coefficient, the green remanufacturer’s collection price is increasing, the green recycler’s collection price is decreasing. Moreover, the collection price in the mixed collection channel is lower than that in the online collection channel. This shows that the green remanufacturer gives lower collection price to the green customers, the green remanufacturer can get higher profit.

Figure 4 illustrates that it has the positive relationship between the preference coefficient and the collection price under three kinds of collection channels. At the same time, the green recycler’s fairness concern coefficient has the positive relationship to the collection price under three collection channels. Moreover, the collection price in the mixed collection channel is lower than that in online or offline collection channels. At the same time, it also can be seen from Figure 5 that the green collector relative fairness concerns coefficient and three kinds of collection channel strategy under the collection price were positively correlated. The relevant data can be seen in Table 2. Further, the mixed collection channel strategy under the collection price is lower than the pure online or offline collection channel strategy under the collection price.

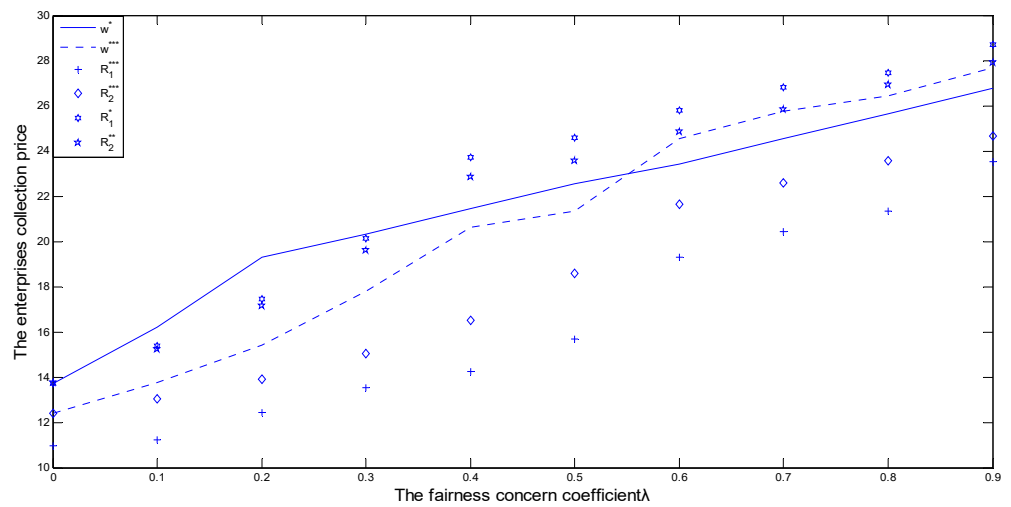


Figure 5. The impact of fairness concern coefficient λ on the collection price $w^*, w^{***}, R_1^*, R_1^{***}, R_2^{**}$ and R_2^{***} .

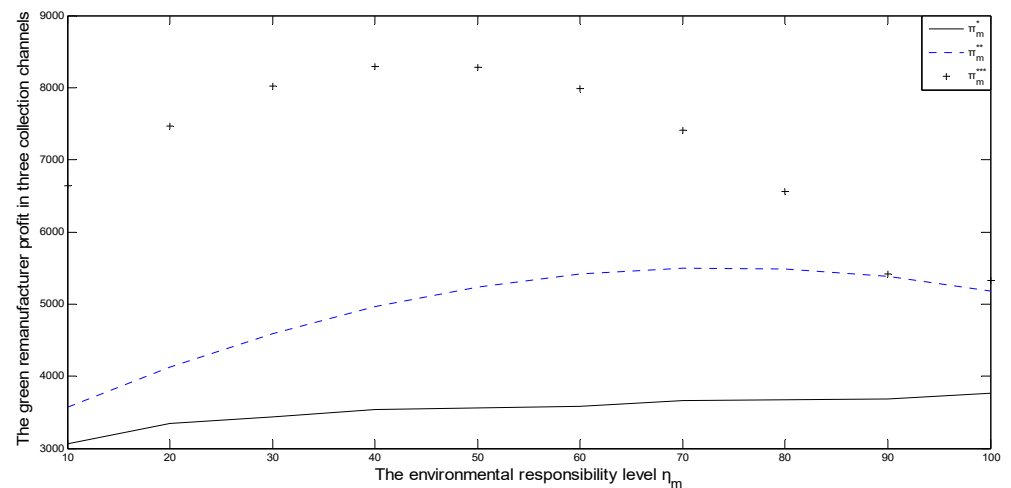


Figure 6. The impact of environmental responsibility η_m on the green remanufacturer's profit $\pi_m^*, \pi_m^{**}, \pi_m^{***}$.

Table 2. The relevant data in Figure 4.

The Preference Coefficient φ	The Collection Price w^*	The Collection Price w^{***}	The Collection Price R_1^{***}	The Collection Price R_2^{**}	The Collection Price R_1^*	The Collection Price R_2^{**}
0	21.53	12.38	3.71	6.80	14.87	13.70
0.1	21.54	12.38	3.71	6.80	14.87	13.70
0.2	21.55	12.39	3.71	6.81	14.88	13.71
0.3	21.55	12.39	3.72	6.81	14.88	13.71
0.4	21.55	12.39	3.72	6.81	14.89	13.71
0.5	21.56	12.39	3.72	6.82	14.89	13.71
0.6	21.56	12.40	3.72	6.82	14.90	13.72
0.7	21.56	12.40	3.73	6.82	14.90	13.72
0.8	21.57	12.40	3.73	6.82	14.91	13.72
0.9	21.57	12.40	3.73	6.83	14.91	13.72

Figure 6 shows that the green remanufacturer's profit has the trend of increasing and then decreasing strategy under different environmental responsibility in three collection channels. Moreover, the green remanufacturer's profit in the mixed collection channel

is higher than that in the online or the offline collection channels. From the angle of the green remanufacturer, the green remanufacturer collects the waste green products using the mixed collection channel has many more advantages than the other two kinds of collection channels.

6.2. Discussion

- (1) From the above numerical analysis, we have found some results. It has the positive relationship between the green remanufacturer's environmental responsibility and the collection price under three kinds of collection channel strategies. This result is similar to the Polat et al. [25], they pointed out that in order to collect more waste electronic and electrical products (WEEE), the remanufacturer could set higher collection prices. As a result, the remanufacturer could undertake much more environmental responsibility.
- (2) From the view point of profit, comparing with the single collection channel, the green remanufacturer should collect the waste green products using the mixed collection channel. However, Hong et al. [33] and Dan et al. [46] have pointed out that the remanufacturer could collect the WEEE using the online collection channel. Because the collection cost was very low in online collection channel in traditional supply chain.

7. Conclusions

In this paper, the green reverse supply chain system consisting of one green remanufacturer and one green collector is built, and the remanufacturer can collect waste green products by using online collection channel or offline collection channels or mixed collection channels. We analyze the green remanufacturer's mixed collection channel strategy problem when the green remanufacturer undertakes the environmental responsibility and the green collector has the fairness concern behavior. We reach the follow conclusions:

- (1) In response to the government's call to protect the environment, the enterprise must further strengthen the consciousness of environmental responsibility and increase the intensity of collection of waste green products. In this case, the green remanufacturer can further improve the collection price, so that it makes more customers participate in the collection activity. Thus, it has a positive relationship between the green remanufacturer's environmental responsibility and the collection price under three kinds of collection channel strategies;
- (2) On the one hand, the green remanufacturer must pay more attention to fulfill the environmental responsibility, it will increase the intensity of collection the waste green product, and improve the collection price, the old green product's remanufacturing cost is lower than the production cost of the new product, and it can improve the green remanufacturer's profits. On the other hand, too much attention to environmental responsibility, it is necessary for the green remanufacturer to further increase investment, it leads to increase the production cost of the green product, and the green remanufacturer's profit has a decline trend;
- (3) The green remanufacturer's profit in the mixed collection channel is higher than that in online or offline collection channels. From the angle of the green remanufacturer, the green remanufacturer collects the waste green products using the mixed collection channel has a greater advantage than the other two kinds of collection channels.

From the research, we can get the following managerial insights:

Managerial insight 1: Not only does the green remanufacturer collect waste green products using offline channels, but it also establishes the online channel for collecting waste green products. When the green remanufacturer establishes online collection channels, they can choose to build their own collection website, or they also can use the existing online collection platform. This can improve the ability to collect waste green products, so as to better undertake environmental responsibility.

Managerial insight 2: In practice, the green remanufacturer, in the protection of their own economic benefits and environmental responsibility, should also pay attention to the green collector's fairness concern. Green remanufacturers can sign a certain contract with the green collector, such as a revenue sharing contract, a profit sharing contract, and so on, and giving the green collector certain economic benefits. Otherwise, it is unfavorable to maximize the whole profit of the reverse green supply chain.

As is known to us, this is the first time for the dual collection channel reverse green supply chain as the research object. Moreover, we introduce the fairness concern and the environmental responsibility into the reverse green supply chain, and analyze the green remanufacturer's mixed collection channel strategy problem by using game model. However, it has some limitations in the paper. Firstly, we only analyze and discuss the collection channel's choice problem in reverse green supply chains under symmetric information. In the future, we should discuss the collection channel's choice in reverse green supply chain under asymmetric information. Secondly, we only analyze the impact of the environmental responsibility on the collection price strategy and on the remanufacturer's profit. In the future, we should discuss the coordination strategy between the remanufacturer and the collector in reverse green supply chains.

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