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Supply Chain Model Based on Concurrent Negotiation Particle Swarm

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Abstract

Due to the uncertainty of the green product market, the manufacturers assume enormous R&D and manufacturing risks. Under such background, the problem regarding the cooperation between the manufacture and the retailer becomes an important factor influencing the decisions and the profits of the two parties. In allusion to such problem, the revenue sharing contract is proposed in this article to promote the deep cooperation between the manufacturer and the retailer. Firstly, in consideration of such factors as product greenness and risk avoidance, the centralized decision-marking model and the manufacturer predominated Stackelberg game model are established, wherein the supply chain efficiency of the latter model is discovered to be less than that of the former model. Therefore, the revenue sharing contract is proposed to coordinate the green supply chain so as to make the overall profit and efficiency of the supply chain reach the corresponding level of the centralized decision-making model. Finally, the numerical experiment is carried out to verify the effectiveness and the reliability of the proposed revenue sharing contract. The experiment result shows that the revenue contract can well coordinate the cooperative relationship between the manufacturer and the retailer and meanwhile maximally improve the utilities and the profits for the two parties.

Keywords: *Green Supply Chain; Risk Avoidance Degree; Product Greenness; Revenue Sharing Contract; Incomplete Information*

1. Introduction

Since the green products are increasingly preferred by consumers, people start to concern a kind of green supply chain mode with the consideration of resource consumption and environmental influence on the basis of existing supply chain [1]. The gradually strict environmental protection laws and regulations and the consumer demands enable the enterprises to start to concern and pay attention to the management practice of the green supply chain. For example, Panasonic, Haier Group, HP, *etc.*, start investing a lot to research, develop and manufacture green refrigerators, green washing machines, green computers, *etc.*, [2] During the green supply chain implementation process, enormous risks are included in green product manufacturing and selling activities. Due to the incomplete information, new product research and development include large uncertainty and may be failed. For example, HP Slate tablet computer is very heavy due to the design and software problems, and Intel processor can make the equipment become hot, so such projects are finally stranded. Obviously, the manufacturers assume enormous research and development failure risks [3]. In order to respond to the incomplete information, enterprises would take relevant measures to avoid the risks brought by incomplete information. Therefore, it is extremely important to research the influence of the risk avoidance degree on the operation of the green supply chain.

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According to relevant research achievements of the scholars at home and abroad, the present research literatures cover: the drive and barrier factors of the green supply chain management [4-5], the influencing factors of the green supply chain management and the influence thereof on the organization performance [6-7], the strategic decision-making model of the green supply chain management [8], the game between the government and the manufacturer of the green supply chain [9, 10], the green supply chain coordination [11-12], *etc.*, However, the risks assumed by the members of the supply chain are all supposed to be neutral in the above literatures for researching the green supply chain, and it is also supposed that there is on incomplete information.

Therefore, under the condition of incomplete information, this article aims at establishing the centralized decision-making model and Stackelberg game model on the basis of considering the risk avoidance of the manufacturer in order to compare and analyze the models and discuss the risk avoidance degree, the product greenness as well as the mutual utility influence of the member enterprises of the supply chain. Meanwhile, the revenue sharing contract is applied to heuristically coordinate such green supply chain. This article is expected to provide theoretical support and reference for the member enterprises of the green supply chain to make corresponding management decision under the condition of incomplete information according to the risk preference of the opposite party.

2. Basic Model and Research Hypothesis

The following hypotheses are made in this article:

(1) The market has two types of products: common product and green product, wherein the price of the common products is p_0 and the greenness of the same is g_0, and the greenness of the green product is g; the higher greenness indicates that the product is more environmentally friendly.

(2) The manufacturer has infinite production capacity, namely: the retailer will not suffer from stock-out. c_m is used to denote the manufacturing cost of the manufacturer for unit green product; c_r is used to denote the marketing and logistic cost of the retailer for unit green product. In order to improve product greenness, it is necessary to increase the research and development investment and improve the technology level. Literature [13] is taken as the reference to suppose that the research and development achievement has quadratic relationship with the research and development investment. Additionally, the total research and development costs are supposed to be assumed by the manufacturer, so the cost for researching, developing and manufacturing the green product is $c_y = \frac{1}{2} z g^2$, wherein z is the research and development influencing factor.

(3) Consumers have different consumption preferences to the green product and the common product, and different consumers expect the products purchased thereby to have different greenness. Therein, θ is used to denote the greenness of the green products purchased by the consumers and θ follows the uniform distribution in the interval $[g_0, g]$.

(4) Different consumers want to pay different product prices. Therein, Ω is used to denote the cost that the consumers are willing to pay for improving one unit of the expected product greenness. When $p_0 + \Omega(\theta - g_0) > p$ is true, namely: the price of the green product is lower than the expected price that the consumers are willing

to pay, the consumers will purchase the green product; or else, they will purchase the common product.

(5) Due to incomplete information, the market demand is uncertain, wherein ε ($\varepsilon \in N\left(0, \sigma^2\right)$) is used to reflect the uncertainty of the market demand. In order to respond to the uncertainty of the market demand, the manufacture and the retailer would take relevant measures to maximally reduce losses and avoid the risks brought thereby, wherein η_m is used to denote the risk avoidance degree of the manufacturer, and the larger risk avoidance degree indicates that the manufacturer is more afraid of risks.

According to the above hypotheses, the critical value θ^* of the expected greenness of the consumers shall meet the following condition:

$$p_0 + \Omega(\theta - g_0) = p$$

Then, we can obtain $\theta^* = g_0 + \dfrac{p - p_0}{\Omega}$.

Namely, the market demand function is $D = N\int_{\theta^*}^{g} \dfrac{1}{g - g_0} d_\theta + \varepsilon = N\left\{1 - \dfrac{p - p_0}{\Omega(g - g_0)}\right\} + \varepsilon$.

The profit function of the manufacturer is as follows:

$$\begin{aligned}\Pi_m &= \left(w - c_m\right) D - \frac{1}{2} z g^2 \\ &= N(w - c_m)\{1 - \frac{p - p_0}{\Omega(g - g_0)} + \varepsilon\} - \frac{1}{2} z g^2\end{aligned}$$

The expected revenue function of the manufacturer is as follows:

$$\begin{aligned}E(\Pi_m) &= E\{(w - c_m) D\} = E\{(w - c_m)\} * E\{D\} - E\{\frac{1}{2} z g^2\} \\ &= N(w - c_m)\{1 - \frac{p - p_0}{\Omega(g - g_0)}\} - \frac{1}{2} z g^2\end{aligned}$$

Since the manufacturer is a risk averter, according to the mean-variance theory [14] and the profit and variance influence, the expected manufacturer utility is as follows:

$$\begin{aligned}U(\Pi_m) &= E(\Pi_m) - \eta_m * Var(\Pi_m) = E\{(w - c_m) D - \frac{1}{2} z g^2\} - \eta_m E[\Pi_m - E(\Pi_m)]^2 \\ &= E\{(w - c_m)\} * E\{D\} + E\{-\frac{1}{2} z g^2\} - \eta_m E[\Pi_m - E(\Pi_m)]^2 \\ &= N(w - c_m)\{1 - \frac{p - p_0}{\Omega(g - g_0)}\} - \frac{1}{2} z g^2 - \eta_m (w - c_m)^2 \sigma^2\end{aligned}$$

Similarly, the profit function of the retailer is as follows:

$$\begin{aligned}\Pi_r &= \left(p - w - c_r\right) D \\ &= \mathrm{N}(p - w - c_r)\{1 - \frac{p - p_0}{\Omega(g - g_0)} + \varepsilon\}\end{aligned}$$

3. Modeling

3.1. Centralized Decision-Making Model

The centralized decision-making model refers to the unified system composed of manufacturer, retailer, *etc.*, in the supply chain, and this system is adopted for centralized decision-making in order to optimize the whole supply chain [15]. Under the centralized decision-making condition, the manufacturer and the retailer cooperate with each other and comprehensively consider revenues and risks to select suitable wholesale price and product price so that the whole supply chain can have maximum expected utility. Under the centralized decision-making condition, the expected utility of the supply chain can be expressed as follows:

$$\mathrm{Max}\,U(\pi_c) = U(\Pi_m) + \Pi_r$$

Namely: $$\mathrm{Max}\,U(\pi_c) = (p - c_r - c_m)\left\{1 - \frac{p - p_0}{\Omega(g - g_0)}\right\} - \frac{1}{2}zg^2 - \eta_m (w - c_m)^2 \sigma^2 \tag{1}$$

HESSE matrix of Formula (1) is as follows:

$$H_1 = \begin{pmatrix} \frac{-2}{\Omega(g-g_0)} & 0 & \frac{2p - p_0 - c_r - c_m}{\Omega(g-g_0)^2} \\ 0 & -2\eta_m\sigma^2 & 0 \\ \frac{2p - p_0 - c_r - c_m}{\Omega(g-g_0)^2} & 0 & \frac{-2\Omega^2 (p - c_r - c_m)(p - p_0)}{[\Omega(g-g_0)]^3} - z \end{pmatrix}$$

Since the above HESSE matrix includes multiple parameters, it is difficult to judge whether the matrix is a negative definite matrix only according to the above hypotheses, thus indicating that the concavity and the convexity of the target function depend on the parameter values. Therefore, we only discuss the condition that the function only has the unique equilibrium solution.

After relevant operation, the following condition can be obtained:

The first-order partial derivatives of Formula (1) for p , w and g are as follows:

$$1 - \frac{2p - p_0 - c_r - c_m}{\Omega(g - g_0)} = 0 \tag{2}$$

$$\eta_m (w - c_m) = 0 \tag{3}$$

$$\frac{(p - c_r - c_m)(p - p_0)}{\Omega(g - g_0)^2} - zg = 0 \tag{4}$$

Formulae (2), (3) and (4) are combined to obtain the optimal wholesale price w^C , the optimal product price p^C and the greenness g^C of the centralized decision-making model:

$$p^C = \frac{\Omega(g^c - g_0) + p_0 + c_r + c_m}{2}$$

$$w^C = c_m$$

In the above formula, g^C is determined by the following implicit function:

$$p^{C^2} - p^C p_0 - p^C(c_r + c_m) + p_0(c_r + c_m) = \Omega z g^C (g^C - g_0)^2$$

Proposition 1 In the centralized decision-making model, the critical value g_1^* of the product greenness can be found to meet the following conditions:

(1) When $g > g^{C*}$ is true, then $p^C > w^C$ is true;

(2) When $g = g^{C*}$ is true, then $p^C = w^C$ is true

(3) When $g < g^{C*}$ is true, then $p^C < w^C$ is true

In the above formulae, $g^{C*} = g_0 + \frac{c_m - p_0 - c_r}{\Omega}$.

Proof: If $p^C > w^C$ is true, then $\frac{\Omega\left(g^C - g_0\right) + p_0 + c_r + c_m}{2} > c_m$ is true.

According to the above formula, $g > g_0 + \frac{c_m - p_0 - c_r}{\Omega}$ can be obtained.

Then, set $g^{C*} = g_0 + \frac{c_m - p_0 - c_r}{\Omega}$

Accordingly, we can prove: when $g > g^{C*}$ is true, $p^C > w^C$ is true; similarly, other conclusions can be proven to be true.

Proposition 2 Under the centralized control mode, the product price p^C is increased along with the increase of the product greenness g^C.

Proof: The first-order partial derivative of $p^{C^2} - p^C p_0 - p^C(c_r + c_m) + p_0(c_r + c_m) = \Omega z g^C (g^C - g_0)^2$ for g^C can be obtained. According to implicate function derivation rule, the following formulae are obtained:

$$2p^c * \frac{\partial p^c}{\partial g^c} - (p_0 + c_r + c_m) = \Omega z (g^c - g_0)^2 + 2\Omega z g^c (g^c - g_0)$$

$$\frac{\partial p^c}{\partial g^c} = \frac{\Omega z (g^c - g_0)(3g^c - g_0) + (p_0 + c_r + c_m)}{2p^c}$$

According to the above hypotheses, if $g^c > g_0$ is true, then $(g^c - g_0)(3g^c - g_0) > 0$ is true.

Therefore, $\frac{\partial p^c}{\partial g^c} > 0$ is true, namely: p^c is an increasing function regarding g^c.

Therefore, the product price p^c is increased along with the increase of the product greenness p^c, q.e.d. This proposition indicates that the research and development cost and the manufacturing cost of the manufacturer are increased along with the improvement of the product greenness, so the manufacturer will transfer such cost increase to the retailer and meanwhile the retailer will transfer part of the cost increase to the consumers, thus increasing the marketing price of the product. Obviously, this is coincident with the practical situation.

3.2. Manufacturer Predominated Stackelberg Game Model

In this Stackelberg game model, the manufacturer occupies a leading position and is accordingly as the principal party, and the retailer is the subordinate party.

Therein, the decision variables of the manufacturer are the wholesale price w and the product greenness g , and the decision variable of the retailer is the product price p . For a given wholesale price w , the retailer determines the optimal product price p and then the manufacturer determines the optimal wholesale price w on the basis of the optimal product price in order to maximize the utility function thereof $U(\pi_m)$. The reverse induction method is adopted to solve the function.

$$MaxU(\Pi_m) = N(w - c_m)\{1 - \frac{p - p_0}{\Omega(g - g_0)}\} - \eta_m(w - c_m)^2\sigma^2 - \frac{1}{2}zg^2 \quad (5)$$

$$s.t. p^* = \arg\max U(\Pi_r)$$

$$Max\Pi_r = N(p - w - c_r)\{1 - \frac{p - p_0}{\Omega(g - g_0)}\} \quad (6)$$

When w is determined, $H_2 = -\frac{2}{\Omega(g - g_0)} < 0$ is true.

The second-order partial derivative of Formula (6) for variable p is obtained as follows:

$$\partial^2\Pi_r / \partial p^2 = -\frac{2}{\Omega(g - g_0)} < 0$$

Obviously, Π_r is a concave function regarding p and has maximum value.

$$\frac{\partial\Pi_r}{\partial p} = \mathrm{N} - \frac{2p - p_0 - c_r - w}{\Omega(g - g_0)}N = 0$$

Then, $p^M = \frac{\Omega(g^M - g_0) + p_0 + w^M + c_r}{2}$ can be obtained.

p^M is put into Formula (5) to obtain the following formula:

$$MaxU(\Pi_m) = N(w^M - c_m)\{1 - \frac{\Omega(g^M - g_0) + w^M + c_r - p_0}{2\Omega(g^M - g_0)}\} - \eta_m(w^M - c_m)^2\sigma^2 - \frac{1}{2}zg^{M^2} \quad (7)$$

Proposition 3 When $\Omega(g^M - g_0) < 4z$ is true, the utility function of the manufacturer is a joint concave function regarding w^M and g^M .

HESSE matrix of Formula (7) is as follows:

$$H_3 = \begin{pmatrix} -\frac{1}{\Omega(g^M - g_0)} & \frac{1}{2} \\ \frac{1}{2} & -z \end{pmatrix}$$

According to this HESSE matrix, $\frac{\partial^2 U(\Pi_m)}{\partial w^2} = -\frac{1}{\Omega(g^M - g_0)} < 0$ and $\frac{\partial^2 U(\Pi_m)}{\partial g^2} = -z < 0$ can be obtained.

Additionally, the condition $\frac{1}{4}-\frac{-1}{\Omega\left(g^{M}-g_{0}\right)}*(-z)<0$ shall be met, and this formula can be converted as $\Omega\left(g^{M}-g_{0}\right)<4z$.

After the first-order partial derivatives of Formula (7) for w and g are obtained, these first-order partial derivatives are set as 0 to obtain the following conditions:

$$\frac{\partial U\left(\Pi_{m}\right)}{\partial w}=N-N\frac{\Omega(g^{M}-g_{0})+\left(2w+c_{r}-p_{0}-c_{m}\right)}{2\Omega(g^{M}-g_{0})}-2\eta_{m}\sigma^{2}\left(w-c_{m}\right)=0 \tag{8}$$

$$\frac{\partial U\left(\Pi_{m}\right)}{\partial g}=N\Omega(w^{M}-c_{m})(w^{M}+c_{r}-p_{0})-2zg\Omega^{2}(g^{M}-g_{0})^{2}=0 \tag{9}$$

Formulae (8) and (9) are combined to obtain the optimal wholesale price w^{M} and the greenness g^{M} of the model to maximize the manufacturer utility.

$$w^{M}=\frac{2\Omega\left(g^{M}-g_{0}\right)\left(N+2c_{m}\eta_{m}\sigma^{2}\right)+\left(c_{m}-c_{r}+p_{0}\right)-N\Omega\left(g^{M}-g_{0}\right)}{2\left\{2\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+N\right\}}$$

In the above formula, g^{M} is determined by the following formula:

$$N\Omega(w^{M}-c_{m})(w^{M}+c_{r}-p_{0})=2z\Omega^{2}g^{M}(g^{M}-g_{0})^{2}$$

Proposition 4 In the manufacturer predominated Stackelberg game model, the wholesale price is reduced along with the increase of the risk avoidance degree of the manufacturer.

$$\frac{\partial w^{M}}{\partial\eta_{m}}=\frac{4c_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)-4\sigma^{2}\Omega\left(g^{M}-g_{0}\right)\left\{2\Omega\left(g^{M}-g_{0}\right)\left(N+2c_{m}\eta_{m}\sigma^{2}\right)+\left(c_{m}-c_{r}+p_{0}\right)-N\Omega\left(g^{M}-g_{0}\right)\right\}}{2\left\{2\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+N\right\}^{2}}$$
$$=\frac{4c_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)-4\sigma^{2}\Omega\left(g^{M}-g_{0}\right)\left\{4c_{m}\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+c_{m}-c_{r}+p_{0}+N\Omega\left(g^{M}-g_{0}\right)\right\}}{2\left\{2\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+N\right\}^{2}}$$
$$=\frac{-4\sigma^{2}\Omega\left(g^{M}-g_{0}\right)\left\{4c_{m}\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+2c_{m}-c_{r}+p_{0}+N\Omega\left(g^{M}-g_{0}\right)\right\}}{2\left\{2\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+N\right\}^{2}}$$

$p_{0}+N\Omega\left(g^{M}-g_{0}\right)>p_{0}+\Omega\left(g^{M}-g_{0}\right)>p$,

$p_{0}+N\Omega\left(g^{M}-g_{0}\right)-c_{r}>p-c_{r}>0$

Proof: Since

$$\frac{\partial w^{M}}{\partial\eta_{m}}=\frac{4c_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)-4\sigma^{2}\Omega\left(g^{M}-g_{0}\right)\left\{2\Omega\left(g^{M}-g_{0}\right)\left(N+2c_{m}\eta_{m}\sigma^{2}\right)+\left(c_{m}-c_{r}+p_{0}\right)-N\Omega\left(g^{M}-g_{0}\right)\right\}}{2\left\{2\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+N\right\}^{2}}$$
$$=\frac{4c_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)-4\sigma^{2}\Omega\left(g^{M}-g_{0}\right)\left\{4c_{m}\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+c_{m}-c_{r}+p_{0}+N\Omega\left(g^{M}-g_{0}\right)\right\}}{2\left\{2\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+N\right\}^{2}}$$
$$=\frac{-4\sigma^{2}\Omega\left(g^{M}-g_{0}\right)\left\{4c_{m}\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+2c_{m}-c_{r}+p_{0}+N\Omega\left(g^{M}-g_{0}\right)\right\}}{2\left\{2\eta_{m}\sigma^{2}\Omega\left(g^{M}-g_{0}\right)+N\right\}^{2}}$$

and $p_{0}+N\Omega\left(g^{M}-g_{0}\right)>p_{0}+\Omega\left(g^{M}-g_{0}\right)>p$ are true, thus $p_0 + N\Omega\left(g^M - g_0\right) - c_r > p - c_r > 0$ is true.

Therefore, $\frac{\partial w^M}{\partial \eta_m} < 0$ is true, namely: the wholesale price is reduced along with the increase of the risk avoidance degree of the manufacturer. In other words, when the manufacturer is more and more afraid of risks, he/she will reduce the wholesale price to promote the retailer to purchase more green products and accordingly avoid the excessive inventory.

3.3. Revenue Sharing Model

In the revenue sharing contract mechanism, the sales revenue sharing proportion of the retailer is φ while that of the manufacturer is $1-\varphi$. Then, the profit function of the retailer can be expressed as follows:

$$\Pi_r = (\varphi p - w - c_r)\{1 - \frac{p - p_0}{\Omega(g - g_0)}\} \tag{10}$$

In the revenue sharing contract mechanism, the revenue of the manufacturer is composed of the wholesale revenue obtained thereby and the risk sharing revenue provided by the retailer. In such model, the expected utility model of the manufacturer can be expressed as follows:

$$U(\Pi_m) = \left[(1-\varphi)p + w - c_m\right]\{1 - \frac{p - p_0}{\Omega(g - g_0)}\} - \eta_m\left[(1-\varphi)p + w - c_m\right]^2\sigma^2 - \frac{1}{2}zg^2$$

In the manufacturer predominated principle/subordinate gaming model, the decision variable of the retailer is the retail price after the wholesale price is determined by the manufacturer. When w is determined, the following formula can be obtained according to Formula (10):

$$\partial^2\Pi_r / \partial p^2 = -2\left(\frac{\varphi}{\Omega\left(g - g_0\right)}\right) < 0$$

Obviously, Π_r is a concave function regarding p. Therefore, the following formula can be obtained:

$$\frac{\partial \Pi_r}{\partial p} = \varphi - \frac{2\varphi p - \varphi p_0 - c_r - w}{\Omega\left(g - g_0\right)} = 0$$

Further, $p = \frac{\varphi\left[\Omega\left(g - g_0\right) + p_0\right] + w + c_r}{2\varphi}$.

Because $p^c = \frac{\Omega\left(g - g_0\right) + p_0 + c_r + c_m}{2}$ is true in the centralized decision-making model, thus $w^c = c_m$ is true.

According to the incentive purpose of the revenue sharing mechanism, only when $p = p^c$ is true, namely: the retail price of the retailer is equal to the retail price during the cooperation, the incentive purpose can be achieved. Therefore, the following formula can be obtained:

$$\frac{\varphi\left[\Omega\left(g - g_0\right) + p_0\right] + w + c_r}{2\varphi} = \frac{\Omega\left(g - g_0\right) + p_0 + c_r + c_m}{2}$$

Further, $w* = \varphi(c_r + c_m) - c_r$ and $p* = \frac{\Omega(g - g_0) + p_0 + c_r + c_m}{2}$ can be obtained.

Namely, $w^* < \varphi c_m$ is proven. Therefore, in the revenue sharing contract mechanism, the manufacturer would wholesale the products to the retailer at the wholesale price lower than the manufacturing cost and the retailer would pay ($1-\varphi$) of the actual sales revenues to the manufacturer as the return.

The effective revenue sharing contract mechanism shall not reduce the revenue of any gaming party. Therefore, when the manufacturer is a risk averter and the retailer is a risk neutral person, the following constraint conditions during the cooperation in the manufacturer predominated principle/subordinate gaming model shall be met:

$$U\left(\Pi_m\left(p^*, w^*\right)\right) \geq U\left(\Pi_m\left(p^{c*}, w^{C*}\right)\right) \tag{11}$$

$$\Pi_r\left(p^*, w^*\right) \geq \Pi_r\left(p^{c*}, w^{C*}\right) \tag{12}$$

4. Numerical Simulation

It can be found in the above modeling process that all formulae are relatively complex. In order to further analyze the scientific property of the model, corresponding values are assigned to the model for relevant simulation. The value assignment is as follows: $N = 200$, $z = 20$, $\Omega = 16$, $p_0 = 13$, $c_r = 5$, $c_m = 8$, $\sigma = 2$ and $g_o = 1$. The simulation analysis is as follows:

(1) Influence of revenue sharing coefficient change: according to Figure 1, the manufacturer utility is continuously reduced along with the increase of the revenue sharing coefficient. Although the manufacturer utility is reduced, within the reasonable revenue sharing coefficient range, the manufacturer utility in the revenue sharing model is always greater than that in the decentralized decision-making model. Therefore, it is believed that the manufacturer can obtain higher utility through revenue sharing. According to Figure 2, the retailer profit is continuously increased along with the increase of the revenue sharing coefficient and the profit in the revenue sharing model is greater than that in the decentralized decision-making model, thus indicating that the retailer can obtain higher profit through revenue sharing. In conclusion, the manufacturer and the retailer would improve their profits and utilities through revenue sharing.

(2) Influence of revenue sharing on wholesale price: according to Figure 3, the wholesale price is continuously increased along with the increase of the revenue sharing coefficient, thus indicating that the manufacturer would improve the wholesale price to increase the utility thereof in the revenue sharing state. Additionally, it can be found that the wholesale price in the revenue sharing state is much less than that in the decentralized state, thus indicating that the manufacturer would actively reduce the wholesale price during the revenue sharing process in order to obtain retailer's trust and find more deep cooperation opportunities.

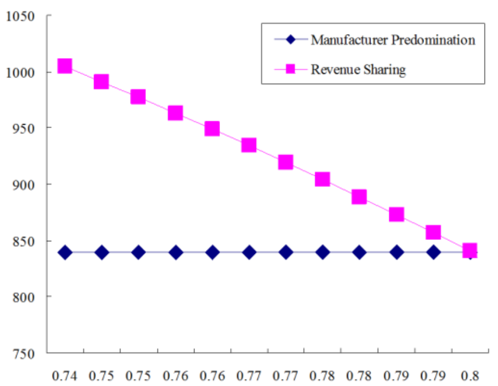

Figure 1. Revenue Sharing Coefficient Based Manufacture Utility Change

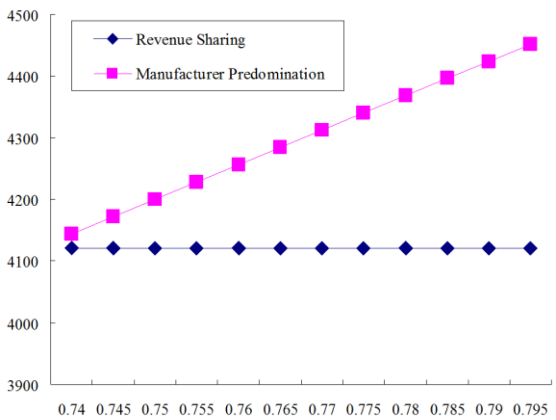

Figure 2. Revenue Sharing Coefficient Based Retailer Profit Change

(3) Influence of risk avoidance coefficient on wholesale price: according to Figure 4, the wholesale price is sharply reduced along with the increase of the risk avoidance coefficient, thus indicating that the manufacturer would reduce the wholesale price when becoming more and more cautious in order to wholesale a lot of products to the retailer as soon as possible and accordingly transfer relevant risks. This is completely consistent with the conclusion in Proposition 4.

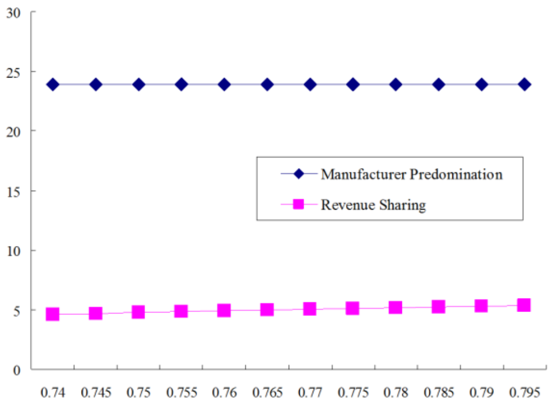

Figure 3. Revenue Sharing Coefficient Based Wholesale Price Change

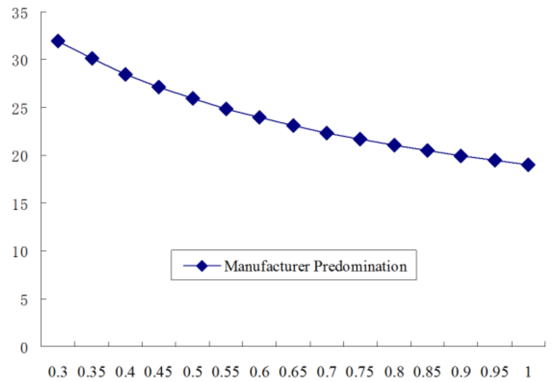

Figure 4. Risk Avoidance Coefficient Based Wholesale Price Change

5. Conclusion

The two-stage green supply chain composed of one manufacturer and one retailer is considered in this article, wherein the manufacturer is a risk averter while the retailer is a risk neutral person. Meanwhile, the centralized decision-making model, the manufacturer predominated Stackelberg game model and the revenue sharing model are also established in this article. The experiment result shows: (1) the critical value g_1^* of the product greenness can be found in the centralized decision-making model; (2) in the manufacturer predominated Stackelberg game model, the wholesale price of the manufacturer is increased along with the increase of the product greenness. Specifically, the centralized decision-making model and the manufacturer predominated Stackelberg game model are mainly considered in this article. In future, the research will be mainly focused on the retailer predominated Stackelberg game model and Nash equilibrium model as well as the comparative analysis of the above two models.

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