Revenue Sharing Contract of the Green Supply Chain Based on Centralized Decision Making and the Game Model

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Abstract
The uncertainty of green product market resulted in that the manufacturer to bear the enormous risks of R & D and manufacturing problems, at the same time, the cooperation of manufacturers and retailers having become an important factor affecting decision and profit of the two. In order to solve this problem, we put forward to use the revenue sharing contract to promote the depth of cooperation between manufacturers and retailers. First of all, we consider the green degree and risk aversion and other factors, constructing the centralized decision-making model and the manufacturer Stackelberg game model, and finding that the the efficiency of the supply chain of latter in will be less than the former. Therefore, we put forward the revenue sharing contract to realize the coordination of the green supply chain, which makes the profit and efficiency of the whole supply chain reach the level of decision-making model. Finally, numerical experiments verified the effectiveness and reliability of the revenue sharing contract proposed in this paper. Experimental results show that the revenue sharing contract can coordinate cooperative relationship between the manufacturer and the retailer well, and can greatly improve the utility and profit of the two.
Key words: GAME THEORY, CENTRALIZED DECISION MAKING, GEEN SUPPLY CHAIN, RISK AVERSION, REVENUE SHARING CONTRACT.

1. Introduction

With the green products increasingly favored by consumers, being as one that based on the supply chain, considering the resource consumption and environmental impact, the green supply chain model starts to attract attention[1]. Increasingly stringent environmental regulations, and changes of the consumer demand, the enterprises start to pay attention to and attach importance to the management practice of the management practicegreen supply chain management. Such as Panasonic appliances, Haier group and HP computer began to research and develop and product green refrigerator, green washing machine and green computer [2]. But in the process of the implementation of the green supply chain, production and sales of green products have a considerable risk. Because of the research and development of new products, due to the incomplete information, a lot of uncertainty of itself, it is likely to fail, such as the HP Slate tablet computers,for design and software problems, making Slate tablet become very heavy, Intel processor making the equipment be hot, finally the project ran aground. Therefore, manufacturers bear the huge risk of R & D failure [3]. In order to deal

with incomplete information, the enterprise will take measures to avoid the risks brought by incomplete information. So, the the impact of risk aversion of research on the operations of green supply chain becomes extremely important.

Making a comprehensive survey on the research results of domestic and foreign scholars, we can find the current research literature covers: drive and obstacle factors of management of the green supply chain[4,5], the influencing factors of the management of green supply chain and the impact on firm performance [6,7], strategic decision model of the management of the green supply chain[8], the game of the government and the maker of green supply chain[9,10], the coordination of green supply chain [11,12] and so on. However, the study of the above literature on green supply chain, all assuming the supply chain members are risk neutral, without considering the incomplete information.

Therefore, this paper will be in the condition of incomplete information, based on considering the risk aversion of the manufacturers, constructing centralized decision-making model and the Stackelberg game model, comparing and analyzing, to explore the interaction between the degree of risk aversion, the product green degree and the utility of the member enterprises of the supply chain. And try to use the revenue sharing contract to coordinate the green supply chain. I hope this paper can give the green supply chain enterprises, under the condition of incomplete information, according to each other's risk preference, formulating the corresponding management decisions, to provide theoretical support and reference.

2. The basic model and the research hypothesis

This paper made the following assumptions:

(1) There are two kinds of products on the market: ordinary products and green products. The price of the common product is p_0 ,the green degree of it being g_0 .The higher the Green degree, indicating that the more environmental protection of the product, the green degree of green products being g .

(2) The manufacturer's production capacity is infinite, the out of stock of the retailer does not occur. Using the c_m to express the production cost of manufacturers of the unit of green products; using c_r to express the marketing logistics cost of unit green product of the retailer. In order to improve the green degree of products, we need to increase research and development investment, improving the technical level. Reference documentation [13], results of R & D and investment of R & D is quadratic relationship. And assuming that, research and development costs are borne by the manufacturer, the cost of R & D of green products being $c_y = \frac{1}{2}zg^2$, z being the impact factor of research and development.

(3) The different consumers having different consumer preferences on the green products and ordinary products , different consumers want to buy the products with different green degree. Using θ to express the green degree of green products the consumers want to buy, and in the interval $[g_0, g]$, θ obeying the uniform distribution.

(4) Different consumers are willing to pay different price of the product. Using Ω the consumer's expectations of product green degree increased by one unit, the cost the consumers are willing to pay. When the $p_0 + \Omega(\theta - g_0) > p$, namely that the price of green product being lower than the expectations of consumers are willing to pay, consumers will buy green products, otherwise they will buy ordinary products.

(5) Because of incomplete information, market demand having uncertainty, using ε to reflect the uncertainty of market demand, $\varepsilon \in N(0, \sigma^2)$. In order to deal with the uncertain of market demand, manufacturers and retailers will take steps to minimize losses, to avoid the risk caused by it. Using η_m to express the degree of risk aversion of the manufacturer; the bigger the risk aversion degree, the more afraid of the risk that the manufacturer.

By the above assumptions, the critical value of expectations of green degree of consumers θ^* should meet:

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

Thus obtained $\theta^* = g_0 + \frac{p - p_0}{\Omega}$

The function of market demand is

$$D = N\int_{\theta^*}^{g} \frac{1}{g - g_0} d_\theta + \varepsilon = N\left\{1 - \frac{p - p_0}{\Omega(g - g_0)}\right\} + \varepsilon$$

The profit function of the manufacturer is

$$\Pi_m = (w - c_m)D - \frac{1}{2}zg^2$$

$$= N(w - c_m)\{1 - \frac{p - p_0}{\Omega(g - g_0)} + \varepsilon\} - \frac{1}{2}zg^2$$

The expected revenue function of the manufacturer is

$$E(\Pi_m) = E\{(w - c_m)D\} = E\{(w - c_m)\} * E\{D\} - E\{\frac{1}{2}zg^2\}$$

$$= N(w - c_m)\{1 - \frac{p - p_0}{\Omega(g - g_0)}\} - \frac{1}{2}zg^2$$

Because the manufacturer is risk aversion, according to the theory of mean variance [14], considering the influence of profit and the variance, the expected utility of the manufacturer is:

$$U(\Pi_m) = E(\Pi_m) - \eta_m * Var(\Pi_m) = E\{(w-c_m)D - \frac{1}{2}zg^2\} - \eta_m E[\Pi_m - E(\Pi_m)]^2$$

$$= E\{(w-c_m)\} * E\{D\} + E\{-\frac{1}{2}zg^2\} - \eta_m E[\Pi_m - E(\Pi_m)]^2$$

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

Similarly, the profit function of the retailer is

$$\Pi_r = (p-w-c_r)D$$

$$= \mathrm{N}(p-w-c_r)\{1 - \frac{p-p_0}{\Omega(g-g_0)} + \varepsilon\}$$

Proposition 2 In centralized controlled system, the product price p^C increased with the increase of product green degree g^C.

Prove For the formula

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

to calculate the first-order partial derivative of g^C. According to the implicit function derivative rule we having

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

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

According to the assuming we know, $g^c > g_0$,so $(g^c - g_0)(3g^c - g_0) > 0$.

So $\frac{\partial p^c}{\partial g^c} > 0$, namely p^c is the function about g^c.

So the product price p^C increased with the increase of product green degree g^C, prove being over.

The proposition that the increase of the green degree of products, the cost of production-manufacturing and research and development will increase, so the manufacturer shifting this part to retailers, retailers shifting this part of the cost to consumers, it will increase the market price of the product, which is consistent with the actual situation.

3. The construction of model

3.1. The centralized decision-making model

Centralized decision making refers to the manufacturers, retailers and other supply chains make up the unified system, made centralized decision by the system, to achieve the optimization of the whole supply chain [15]. In the condition of centralized decision making, manufacturers cooperating with retailers, based on the comprehensive consideration of the return and risk to select the appropriate wholesale price and product price making the whole supply chain have maximizing the expected utility. Under centralized decision-making, the expected utility of supply chain can be expressed as:

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

Namely

$$\mathrm{Max}U(\pi_c) = (p - \mathrm{c}_r - c_m)\left\{1 - \frac{p-p_0}{\Omega(g-g_0)}\right\} - \frac{1}{2}zg^2 - \eta_m(w-c_m)^2\sigma^2 \quad (1)$$

The Hessian matrix (HESSE) of formula (1)

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

Due to the HESSE matrix containing a number of parameters, only through the above hypothesis, it is difficult to determine whether the matrix is negative definite matrix, illustrating that the concave and convex of the objective function should depend on the values of various parameters. Therefore, here we only discuss the existence of uniqueness of the equilibrium solution of the function.

Sorting out conditions as follows:

Respectively calculating the first-order derivative of p, w, g ,we can obtain

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

$$\eta_m(w-c_m)=0 \quad (3)$$

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

Through the simultaneous equations of formula (2) (3) (4), we can get the optimal wholesale price w^C ,the optimal product price p^C and green degree g^C of the centralized decision-making model are respectively:

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

$$w^C=c_m$$

In which, g^C is determined by the 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 model, there exists a critical value of product green degree g_1^* , making

When $g>g^{C*}$, $p^C>w^C$;

When $g=g^{C*}$, $p^C=w^C$;

When $g<g^{C*}$, $p^C<w^C$;

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

Proving that if $p^C>w^C$, there are

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

From the above formula we can obtain $g>g_0+\frac{c_m-p_0-c_r}{\Omega}$

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

Through this prove we can obtain, when $g>g^{C*}$, $p^C>w^C$; In the same way other conclusions can be proved to be established.

Proposition 2 In centralized controlled system, the product price p^C increased with the increase of product green degree g^C .

Prove For the formula

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

to calculate the first-order partial derivative of g^C .

According to the implicit function derivative rule we having

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

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

According to the assuming we know, $g^c>g_0$,so $(g^c-g_0)(3g^c-g_0)>0$.

So $\frac{\partial p^c}{\partial g^c}>0$, namely p^c is the function about g^c .

So the product price p^C increased with the increase of product green degree g^C , prove being over. The proposition that the increase of the green degree of products, the cost of production-manufacturing and research and development will increase, so the manufacturer shifting this part to retailers, retailers shifting this part of the cost to consumers, it will increase the market price of the product, which is consistent with the actual situation.

3.2. The game model of manufacturer led Stackelberg

In the Stackelberg game model, the manufacturer dominates the main square, retailers being the following party. Among them, the manufacturer's decision variables is wholesale price w and the green degree of products g , retailer's decision variable is the product price p . For the given wholesale price w ,the retailer determining the optimal product price p , the manufacturer based on the optimal product price to determine the optimal wholesale price w to maximize the utility function. We use backward induction method to solve.

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

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

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

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

For formula (6) to calculate second-order partial derivative of p variable to obtain:

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

We can know that Π_r is the concave function of p , having a maximum value.

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

Obtained $p^M=\frac{\Omega(g^M-g_0)+p_0+w^M+c_r}{2}$

Put p^M into formula (5) we can obtain

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

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

The Hessian matrix (HESSE) of formula (7)

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

According to the HESSE matrix, we can obtain

$$\frac{\partial^2 U(\Pi_m)}{\partial w^2} = -\frac{1}{\Omega(g^M - g_0)} < 0, \quad \frac{\partial^2 U(\Pi_m)}{\partial g^2} = -z < 0$$

In addition, it should meet $\frac{1}{4} - \frac{-1}{\Omega(g^M - g_0)} * (-z) < 0$, sorted and obtained $\Omega(g^M - g_0) < 4z$

Respectively calculated the first order partial derivative of w and g on (7), making the first-order partial derivative be equal to 0, sorted and obtained the conditions as follows:

$$\frac{\partial U(\Pi_m)}{\partial w} = N - N\frac{\Omega(g^M - g_0) + (2w + c_r - p_0 - c_m)}{2\Omega(g^M - g_0)} - 2\eta_m\sigma^2(w - c_m) = 0 \quad (8)$$

$$\frac{\partial U(\Pi_m)}{\partial g} = N\Omega(w^M - c_m)(w^M + c_r - p_0) - 2zg\Omega^2(g^M - g_0)^2 = 0 \quad (9)$$

Through the simultaneous equations of (8), (9), we can obtain the optimal wholesale price w^M, the green degree g^M, maximizing the utility of manufacturer.

$$w^M = \frac{2\Omega(g^M - g_0)(N + 2c_m\eta_m\sigma^2) + (c_m - c_r + p_0) - N\Omega(g^M - g_0)}{2\{2\eta_m\sigma^2\Omega(g^M - g_0) + N\}}$$

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 led Stackelberg game model, the wholesale price increases with the increase of the degree of risk aversion of manufacturer.

Proof: due to

$$\frac{\partial w^M}{\partial \eta_m} = \frac{4c_m\sigma^2\Omega(g^M - g_0) - 4\sigma^2\Omega(g^M - g_0)\{2\Omega(g^M - g_0)(N + 2c_m\eta_m\sigma^2) + (c_m - c_r + p_0) - N\Omega(g^M - g_0)\}}{2\{2\eta_m\sigma^2\Omega(g^M - g_0) + N\}^2}$$

$$= \frac{4c_m\sigma^2\Omega(g^M - g_0) - 4\sigma^2\Omega(g^M - g_0)\{4c_m\eta_m\sigma^2\Omega(g^M - g_0) + c_m - c_r + p_0 + N\Omega(g^M - g_0)\}}{2\{2\eta_m\sigma^2\Omega(g^M - g_0) + N\}^2}$$

$$= \frac{-4\sigma^2\Omega(g^M - g_0)\{4c_m\eta_m\sigma^2\Omega(g^M - g_0) + 2c_m - c_r + p_0 + N\Omega(g^M - g_0)\}}{2\{2\eta_m\sigma^2\Omega(g^M - g_0) + N\}^2}$$

$$p_0 + N\Omega(g^M - g_0) > p_0 + \Omega(g^M - g_0) > p, \text{ so } p_0 + N\Omega(g^M - g_0) - c_r > p - c_r > 0$$

So $\frac{\partial w^M}{\partial \eta_m} < 0$. Therefore with the increase of the degree of risk aversion of manufacturers, wholesale prices are getting lower and lower.

This can be explained that when manufacturers being more and more afraid of risk, they will reduce the wholesale price to promote the retailer to buy more green products, to avoid the product backlog.

3.4. The model of revenue sharing

In the revenue sharing contract mechanism, the ratio of the retailer share sales revenue being φ, the manufacturer's share ratio being $1-\varphi$. Retailers' profit function can be expressed as

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

In the revenue sharing contract, the income of the manufacturer is consisted by the benefit of the

wholesale and the sharing risk return provided by the retailer.

The expected utility function of the manufacturer can be expressed as

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

In the manufacturer led Stackelberg model, the retailer's decision variables is the retail price under the determined wholesale price of the manufacturer. When w being determined, we can obtain from the formula (10)

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

We can know, Π_r is the concave function of p, so

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

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

And because in the centralized decision-making model $p^c=\frac{\Omega(g-g_0)+p_0+c_r+c_m}{2}$, $w^c=c_m$

According to the incentive purpose of revenue sharing mechanism, only when $p=p^c$, that is the retail price of the retailed and the retail price of the cooperative are equal, the purpose of incentive can be reached. So having

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

Obtained $w^*=\varphi(c_r+c_m)-c_r$,

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

We can prove $w^*<\varphi c_m$. Therefore, in the revenue sharing contract mechanism, manufacturers will wholesale the products as the price lower than the manufacturing cost to retailers, and retailers will take $1-\varphi$ of the actual sales revenue share as return to pay to manufacturers.

Effective coordination mechanism of revenue sharing contract should make the benefit of any party of the gamedo not reduce. Therefore, when the manufacturer being the risk averse, the retailer being risk neutral, when cooperation game model, the required constraints of the manufacturer led Stackelberg model should meet when cooperate:

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

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

4. Numerical Simulation

In the establishment of the previous model, we can find that the formula is more complex. In order to further analyze the scientificalness of the model, we took numerical simulation on the model. The situation of the assignment is as follows: $N=200$, $z=20$, $\Omega=16$, $p_0=13$, $c_r=5$, $c_m=8$, $\sigma=2$, $g_o=1$, now taking simulation analysis.

(1) The influence of the change of the coefficient of revenue sharing. We can see from the figure 1, with the increase of coefficient of revenue sharing, the utility of manufacturers continue to fall. Going a step further, we can see, although the utility of manufacturer decreases, the coefficient of revenue sharing is in a reasonable range, the utility of manufacturer of the revenue sharing model being always greater than the utility of decentralized decision. Therefore, we can think that by revenue sharing, the manufacturer can obtain higher utility. It can be seen from Figure 2, with the increase of the coefficient of revenue

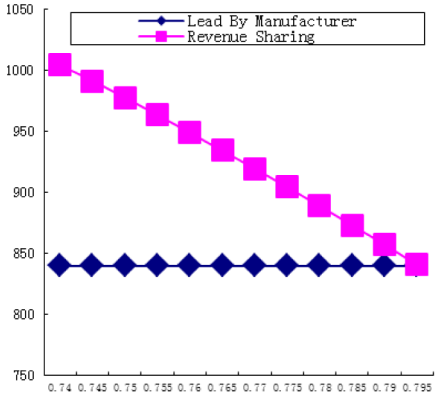

Figure 1. The change of the utility of manufacturer profit of retailers with the with the coefficient of revenue sharing

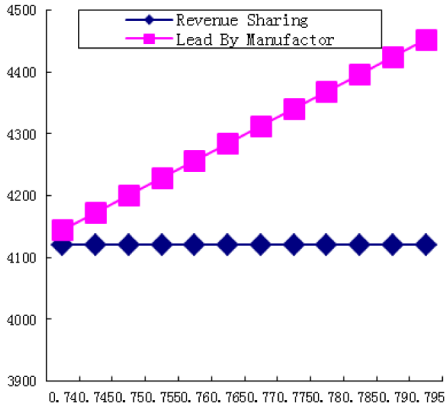

Figure 2. The change of the coefficient of revenue sharing

sharing, the profit of retailers being increasing, and the profit of the revenue sharing model being bigger than the profit of the dispersion state. It shows that by the revenue sharing, the retailer can get more profits. Therefore, manufacturers and retailers are willing to share the benefits, to improve their profit and utility.

(2) The influence of coefficients of revenue sharing on the wholesale price. Figure 3 shows that, with the increase of the coefficients of revenue sharing, wholesale prices also increasing, showing that in the condition of revenue sharing, manufacturers to increase their utility by raising wholesale price. In addition, we can find that the wholesale price under the condition of the revenue sharing is far less than the wholesale price in the dispersion state. It shows that in the process that the revenue sharing, manufacturers will actively reduce the wholesale price to gain the trust of retailers to get more in-depth cooperation.

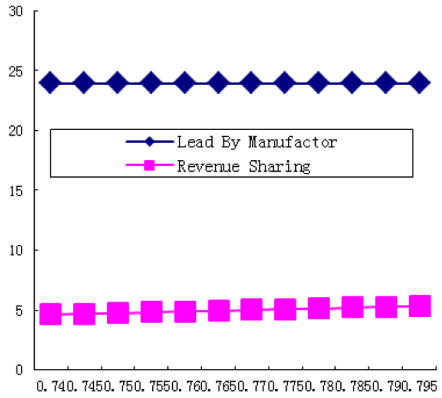

Figure 3. The change of the wholesale price price with the with the coefficient of revenue sharing aversion

(3) The influence of the coefficient of risk aversion on the whole price. In figure 4, the whole price decreased sharply with the increase of risk aversion. It shows that with the manufacturers being more cautious and lowing the whole price, so to wholesale the great mount of products to retailers to transfer the risk, it being consistent with the conclusion of figure (4).

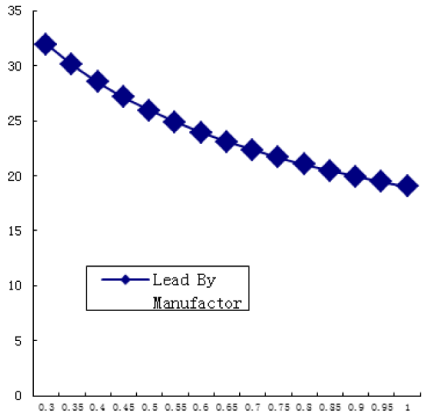

Figure 4. The change of the wholesale coefficient of risk

5. Conclusion

This paper considers, considering the second-level green supply chain composed by a manufacturer and a retailer, the manufacturer being risk averse, the retailer being risk neutral. Establishing the centralized decision-making model, the manufacturer led Stackelberg game model and the revenue sharing model. The experimental results show that: (1) in the centralized model, there exists a critical value of product green degree g_1^*; (2) the manufacturer led Stackelberg game model, the higher the green degree of products, the manufacturer's wholesale price increasing. In this paper, the main consideration is the centralized decision-making model and the manufacturer led Stackelberg game model, the next research direction is further to consider the retailers led Stackelberg game model and the Nash balancing model, analyzing and comparing them.

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