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Research Article

The Incentive Mechanism of Green Supply Chain for Raw Material Procurement

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Abstract: To promote the development of green products' market, the Green Supply Chain (GSC) is a key tool for enterprises. The reasonable coordinating and incentive mechanisms between the members in the GSC are helpful for the effective operation of GSC. For a two-echelon GSC system including a manufacturer and a supplier, the green degree of raw material is the private information for the supplier. To solve this asymmetric information problem, an incentive mechanism is designed by applying the transfer payment method as well as the optimal control theory. It indicates that the proposed mechanism can reveal the real green degree of raw material provided by the supplier and achieve the mutually beneficial maximization as far as possible. The conclusions have good guidance values for the GSC's operation at initial stage of the green market.

Keywords: Adverse selection, green supply chain, incentive mechanism, raw material procurement, revelation principle

INTRODUCTION

The Green Supply Chain (GSC) is a modern management and operation mode that considers the resource economizing and the environment protection simultaneously (Samir, 2007). The GSC is required to achieve products' environmental compatibility in its whole life cycle. The green degree of final product is related to manufacture's production process, environment management factors, most importantly, it is decided by the green degree of raw materials provided by suppliers. Therefore, to provide green products that make customers satisfied and promote the GSC's operation effectively for manufacturer, one of the key steps is to purchase the suitable green raw material from its suppliers.

In actual operation of GSC, manufacturers could usually detect the green degree of raw material or intermediate goods easily for green products which have low technical contents such as the textile and the furniture (Herein the green degree involves the manufacturing technology of intermediate goods or final product, the R&D capability of green technology, material's components and so on). For such intermediate goods, the cost for detect its green degree is relatively not so high. While for green products that have higher technology requirements, like medical products such as porcelain teeth and biological products, once the intermediate goods are made, it is difficult for the testing institutions to test their ingredients and technological levels that related to the green degree. The final products' influence to the customer and the environment couldn't be observed in a short time. For these goods, the suppliers usually know their green degree. While for manufacturers, it is difficult for them to acquire its green degree, or should cost huge testing fee to know its green degree in a short period of time. In these circumstances, the manufacturer should design incentive mechanism to let supplier to tell the truth, to let supplier show the exact green degree and maximize manufacturer's profit.

The research studies those regarding these issues are very rare at present. Related research literature can be divided into two categories. One is green supply chain's incentive mechanism between members. Based on social responsibility for different way, Koplin and Seuring (2007) put forward two incentive mechanism design method between members to achieve the sustainable development of the supply chain. In seven different situations, Wang *et al*. (2009) designed the incentive contracts between the enterprise members in the remanufacturing supply chain. Under the condition of the government environmental regulation, Sheu (2011) analyzed the promoting function of several different mode of enterprise members' incentive mechanism to the GSC's operation based on Taiwan's electronics industry. The other is the material procurement in supply chain's operation and decision-making. Based on the actual cases of steel enterprises, Liu (2010) analyzed the raw materials procurement procedures with a better method under the environment of supply chain. Zhu and Zhu (2012) set up a Stackelberg game model to discuss the optimal decision-

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making under centralized control and decentralized control. All above researches provide a lot of reference for this research study.

Based on the two-echelon GSC system composing of one manufacturer and one supplier, the study applies the transfer payment method and the optimal control theory to design manufacturer's incentive mechanism with information asymmetry on the green degree of raw material provided by the supplier. The proposed incentive mechanism can truly reveal the green degree of supplier's raw material, so it can make the GSC operate effectively. The conclusions give reference values for green market's development and GSC's operation.

Definitions and assumptions of the research: It is assumed that the manufacturer produces a certain kind of green product and its green intermediate goods are provided by its upstream supplier. It supposes that one green product is made of one green intermediate goods and the green degree of the product primarily depends on the intermediate goods. To simplify the analysis of the problem, we assume that the manufacturer and the supplier are both risk-neutral. We ignore the impact of intermediate goods' green degree by the production process, thus the final product's green degree is consistent with the green degree of the intermediate goods.

At the early stage of the green market, we consider that not only is the demand for green products q related to its market price p, but it also is related to the green degree g. Thus:

$$q = q(p, g)$$

it satisfies $q_p<0$, $q_{pp}\geq0$, $q_g>0$ and $q_{gg}\leq0$. Herein we simplistically assume that q = a - bp + hg, a, b, h>0, then:

$$p = \frac{a}{b} - \frac{1}{b}q + \frac{h}{b}g = a_1 - a_2 q + a_3 g \quad (1)$$

obviously, $a_1 = a/b$, $a_2 = 1/b$, $a_3 = h/b$, $a_1, a_2, a_3>0$.

We take the manufacturer as the principal and take the upstream supplier as the agent to research the manufacturer how to design the incentive mechanism when the green degree of intermediate goods is private information of the supplier. Not only can the designed incentive mechanism reveal the supplier's real level of green degree, but it also can let the manufacturer make profit as much as possible.

It is assumed that the manufacturer's marginal cost of production is c_M and the order of the intermediate goods is consistent with the demand of green product, both of them are q. The transfer payment that the manufacturer gives it to supplier is t, so the manufacturer's profit is:

$$\pi_M = (p - c_M)q - t = (a_1 - c_M - a_2 q + a_3 g)q - t \quad (2)$$

Meanwhile, the manufacturer's product quantity should meet:

$$IR_{\pi_M}: q \in [q_L, q_H] \quad (3)$$

The constraint given in Eq. (3) is the individual rational constraint of the manufacturer's production capacity. In Eq. (3), q_L means the lowest manufacturer's production capacity and q_H means the highest capacity.

Further, we use the quadratic constraint of manufacturer's order quantity to replace Eq. (3) (Hou, 2005), that is:

$$\pi_{M,IR} = \frac{1}{2}b_1(q - q_L)^2 + \frac{1}{2}b_2(q_H - q)^2 \quad (4)$$

where,

b_1, b_2 = The lowest and the highest capacity coefficient of rational constraint of the manufacturer's production capacity respectively, $b_1, b_2>0$

Thus, we can transform the objective function of the manufacturer into a general form, using π'_M as the following:

$$\pi'_M = \pi_M - \pi_{M,IR} = (a_1 - c_M - a_2 q + a_3 g)q$$
$$-t - \frac{1}{2}b_1(q - q_L)^2 - \frac{1}{2}b_2(q_H - q)^2 \quad (5)$$

Then, the profit of the supplier is analyzed. Its profit function follows:

$$\pi_S = t - c_S q \quad (6)$$

where,

c_S = The supplier's marginal cost of the green intermediate goods

c_S = The function of g, $c_s = c_s(g)$. It satisfies $c_s'>0$ and $c_s''\geq0$

In order to simplify the description, let:

$$c_s(g) = \frac{1}{2}kg^2$$

where,
K = The cost coefficient of the green intermediate goods, k>0

We suppose that the function structure of c_S is the public knowledge. We gain the profit function for supplier:

$$\pi_S = t - \frac{1}{2}kg^2 q \tag{7}$$

The following discusses the design of the manufacturer's incentive mechanism under symmetric information and asymmetric information conditions respectively.

THE INCENTIVE MECHANISM UNDER THE CONDITION OF SYMMETRIC INFORMATION

Under the condition of symmetric information, the manufacturer can observe the supplier's related information on the green degree of intermediate goods. In order to ensure the successful completion of the agent task, the profit of supplier provided by the manufacturer is not less than π_0 which is the retained profit of the supplier when it does not take part in the task. π_0 can be also considered that the supplier will not accept the entrusted task but accept other task for the lowest income. Herein we let $\pi_0 = 0$, because under the symmetric information, any manufacturer can make the supplier reserve for zero income in order to meet the requirement of its own income optimization. The incentive mechanism problem designed by the manufacturer can be expressed as the following programming Problem (P1):

$$\text{(P1):} \quad \max_{\{t,q\}} \pi'_M = \left(a_1 - c_M - a_2 q + a_3 g\right) q - t$$

$$-\frac{1}{2}b_1\left(q - q_L\right)^2 - \frac{1}{2}b_2\left(q_H - q\right)^2$$

$$s.t. \quad \pi_S = t - \frac{1}{2}kg^2 q \geq 0 \tag{8}$$

where, Eq. (8) is the Individual Rationality constraint (IR) of the supplier.

According to the Incentive Theory (Laffont, 2002), the manufacturer as the principal can control the behavior of the agent through a complete contract and make this kind of behavior and the objective function are in agreement. To achieve the optimal order, the manufacturer can provide the following way of the contract to the supplier, either accept, or leave. At this point, if the supplier accepts the contract, its acquisition of the transfer payment meets:

$$t = \frac{1}{2}kg^2 q \tag{9}$$

Taking Eq. (9) into the objective function of the programming Problem (P1), the problem under symmetric information can be considered as a joint optimal decision-making problem:

$$\max_{\{q\}} \pi'_M = \left(a_1 - c_M - a_2 q + a_3 g\right) q - \frac{1}{2}b_1\left(q - q_L\right)^2$$

$$-\frac{1}{2}b_2\left(q_H - q\right)^2 - \frac{1}{2}kg^2 q \tag{10}$$

According to the manufacturer's first-order condition $\partial\pi'_M/\partial q = 0$, we get:

$$q^S(g) = \frac{1}{2a_2 + b_1 + b_2}$$

$$\left(a_1 - c_M + b_1 q_L + b_2 q_H + a_3 g - \frac{1}{2}kg^2\right) \tag{11}$$

where the superscript S is the result under the symmetric information. Take Eq. (11) into (9), we obtain:

$$t^S(g) = \frac{kg^2}{2\left(2a_2 + b_1 + b_2\right)}$$

$$\left(a_1 - c_M + b_1 q_L + b_2 q_H + a_3 g - \frac{1}{2}kg^2\right) \tag{12}$$

Conclusion 1: In the case of g for symmetric information, $\{q^s(g), t^s(g)\}$ is the contract provided to the supplier by the manufacturer. It indicates that the transfer payment of the supplier is only the summation of production costs. The supplier can't obtain the extra income from the manufacturer.
We can also get:

$$\frac{dq^S(g)}{dg} = \frac{1}{2a_2 + b_1 + b_2}\left(a_3 - kg\right) \tag{13}$$

$$\frac{d^2 q^S(g)}{dg^2} = -\frac{k}{2a_2 + b_1 + b_2} < 0 \tag{14}$$

Conclusion 2: Under the condition of symmetric information, the manufacturer's order $q^s(g)$ is a concave function that has a maximum value. When g = a_3/k, q^s (g) get its maximum value. Thus, it is not always the case that the higher the green degree of supplier's intermediate goods, the bigger the order of the manufacturer.

THE INCENTIVE MECHANISM UNDER THE CONDITION OF ASYMMETRIC INFORMATION

The green degree of intermediate goods provided by the supplier is hidden and cannot be observed by the manufacturer under asymmetric information. According to the revelation principle in the Incentive Theory (Laffont, 2002), the manufacturer is able to design the incentive contract to reveal the true level of green degree of intermediate goods and try to meet the demands of mutual interests as far as possible. It is a typical problem of the adverse selection. When the agent's information is hidden we can transfer the problem of incentive mechanism design into the problem of optimal control.

Firstly, we consider the objective function of the manufacturer, when supplier's information is hidden. The manufacturer's objective function can be expressed as the following expectation function:

$$\max_{\{t,q\}} E\pi'_M = \int_{\underline{g}}^{\overline{g}} \pi'_M f(g)\,dg \tag{15}$$

where, g∈ $[\underline{g}, \overline{g}]$ which obeys the probability density function f(g) and the probability distribution function of g is F(g). Thus, under asymmetric information, the designed problem of manufacturer's incentive mechanism can be expressed as the following programming Problem (P2):

$$\text{(P2):}\quad \max_{\{t,q\}} E\pi'_M = \int_{\underline{g}}^{\overline{g}} \Big[\left(a_1 - c_M - a_2 q + a_3 g\right)q - t - \frac{1}{2}b_1\left(q-q_L\right)^2 - \frac{1}{2}b_2\left(q_H - q\right)^2\Big] f(g)\,dg$$

$$s.t.\ \arg\max_{\{\hat{g}\}} \pi_S = \arg\max_{\{\hat{g}\}}\left[t\left(\hat{g}\right) - \frac{1}{2}kg^2 q\left(\hat{g}\right)\right] \tag{16}$$

where, Eq. (8) is still the Individual Rationality constraint (IR) of the supplier, Eq. (16) is the Incentive Compatibility constraint (IC) of the supplier. In Eq. (16), $\hat{g}$ is the estimated value of g by the manufacturer. According to the revelation principle, we can let the first-order condition of the supplier be zero, i.e., make derivation of Eq. (16) for $\hat{g}$, thus we get:

$$\dot{t} = \frac{1}{2}kg^2 u \tag{17}$$

$$\dot{q} = u \tag{18}$$

Herein we introduce the control variables u, its mechanism significance is the order quantity for the marginal role of intermediate goods' green degree. As a result, the incentive mechanism designed by the manufacturer under asymmetric information can be transformed into an optimal control problem. In this optimal control problem, the variable g gets closer and even reaches the its real value. The objective function is still Eq. (15), the state-space equations are Eq. (17) and (18) where, t(g), q(g) are the state variables and u(g) is the control variable. According to the maximum principle, the Hamiltonian function of the problem is:

$$H = \left[\left(a_1 - c_M - a_2 q + a_3 g\right)q - t - \frac{1}{2}b_1\left(q-q_L\right)^2 - \frac{1}{2}b_2\left(q_H - q\right)^2\right] f(g) + \lambda_t\left(\frac{1}{2}kg^2 u\right) + \lambda_q u \tag{19}$$

where, λ_t and λ_q are the co-state variables. The control equation of the problem is:

$$\frac{\partial H}{\partial u} = \frac{1}{2}kg^2\lambda_t + \lambda_q = 0 \tag{20}$$

The association equations of the problem are:

$$-\frac{d\lambda_t}{dg} = \frac{\partial H}{\partial t} = -f(g) \tag{21}$$

$$-\frac{d\lambda_q}{dg} = \frac{\partial H}{\partial q} = \left[-a_2 q + a_1 - c_M - a_2 q + a_3 g - b_1\left(q - q_L\right) + b_2\left(q_H - q\right)\right] f(g) \tag{22}$$

From Eq. (21) we get λ_t = F (g). It is obtained that:

$$\lambda_q = -\frac{1}{2}kg^2 F(g) \tag{23}$$

Then it satisfies:

$$-\frac{d\lambda_q}{dg} = kgF(g) + \frac{1}{2}kg^2 f(g) \tag{24}$$

Combined Eq. (22) with (24), we obtain:

$$q^A(g)=\frac{1}{2a_2+b_1+b_2}\Big[a_1-c_M+b_1q_L+b_2q_H$$

$$+a_3g-\frac{1}{2}kg^2-\frac{kF(g)}{f(g)}g\Big] \quad (25)$$

where, the superscript *A* indicates that the results under asymmetric information. By calculating Eq. (17) and (18), it is gotten that the transfer payment meets:

$$t'\left(q^A\right)=\frac{1}{2}kg^2\frac{dq^A}{dg} \quad (26)$$

Conclusion 3: Under the condition that *g* is the private information of supplier, $\{q^A$ (g, t^A (g)$\}$ is the contract provided by the manufacturer to the supplier. In view of the different supplier (the green degree of intermediate goods is different), only when it selects the corresponding contract of *g* can it maximizes its profit.

Comparing Eq. (25) with (11) and let $\Delta q(g) = q^S(g) - q^A(g)$, we get:

$$\Delta q(g)=\frac{k}{2a_2+b_1+b_2}\cdot\frac{F(g)}{f(g)}g \quad (27)$$

$$\frac{d\Delta q(g)}{dg}=\frac{k}{2a_2+b_1+b_2}\left[\frac{d}{dg}\left(\frac{F(g)}{f(g)}\right)\cdot g+\left(\frac{F(g)}{f(g)}\right)\right] \quad (28)$$

Conclusion 4: $\Delta q(g) = q^S(g) - q^A(g) > 0$, is satisfied by the analysis of Eq. (27). For the supplier with specific green degree *g*, when the information is hidden, the order quantity is less than that when the information is public. We can conclude that under the condition of asymmetric information, the optimal allocation of resources is distorted. From Eq. (28), we know that if the condition of monotone hazard rate is valid, i.e., $d(F(g)|f(g))|dg \geq 0$, it is satisfied that $d\Delta q(g)|dg \geq 0$. It indicates that when the green degree of intermediate goods increases, the difference between the quantities under symmetric information and asymmetric information continues to increase.

CONCLUSION

The appropriate green raw material is the key factor for the manufacturer to produce the high-quality green product. In view of the adverse selection caused by the upstream supplier hiding the green degree of raw material and according to the revelation principle, we combine the transfer payment method with the optimal control theory to discuss the design of incentive mechanism by the manufacturer in the study. Not only can the proposed incentive mechanism reveal the supplier's real level of the green degree, but it also can let the manufacturer make profit as much as possible. The study has a good guiding significance to the relevant decision-making of the purchase for raw material between the members of GSC at the initial stage of green market.

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