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Incentive Mechanism of Green Supply Chain to Promote Supplier's Technology R&D

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Abstract: Based on the actual situation that the green market started to develop in China today, how to enhance the activity of supplier's technology R&D is discussed in the study. According to a two-echelon supply chain system consists of a manufacturer and a supplier, under the asymmetric information of supplier's R&D efforts level, the incentive mechanism for supplier to improve the green degree of intermediate goods is designed. The proposed incentive mechanism can stimulate the supplier's R&D effort level at its maximum and achieve the system revenue as much as possible. The conclusion has a good practical guidance to operational decision-making of the members of green supply chain in the early green market.

Keywords: Green supply chain, incentive mechanism, moral hazard, supplier, technology R&D

INTRODUCTION

The green supply chain is a kind of modern management mode that integrated considers the resources allocation efficiency and the environmental impact throughout the supply chain (Samir, 2007). The mode requires the environmental compatibility of their products throughout the life cycle. In the actual operation of green supply chain, due to the individual rationality that the member companies would pursue their own income maximization, in the process of collaborative transactions, they would often conceal some private information to get more profits during the negotiations. Due to the prevalence of information asymmetry between member companies within the chain, the incentive mechanism design problems become important issues facing in the process of green supply chain operations. Based on the actual situation, this study considered the passivity of the upstream suppliers' technology R&D and researched the incentive mechanism design problem to promote suppliers' green technology R&D.

For the realization from common products to the green products, green technology research and development (R&D) is the key. Green technology R&D involves not only the manufacturers, but also the suppliers to improve the research and innovation ability. In the green supply chain operations, the incentives that the manufacturer to the upstream suppliers can be roughly divided into two situations:

- For the continuous development of green product market, in order to improve the intermediate or raw materials' quality and green degrees, so as to improve the green degree of the finished products and expand the market share of the green products, so the incentive mechanism is that the manufacturers to the suppliers to improve the green degrees of the intermediate by technology R&D.
- Suppliers already have the ability to produce green intermediate goods, but the production costs are relatively high, so the green product's market price is high and sales volume is low. Therefore, the incentive mechanism is that the manufacturers to the suppliers to reduce production costs by technology R&D.

Whether it is to improve the green degree or to reduce the production costs of the intermediate goods, the R&D work both needs the supplier. In general, the suppliers know their own efforts and costs, but the manufacturers are difficult to view the efforts level of the suppliers. So the transactions between manufacturer and supplier have moral hazard problems. The manufacturers need to design incentive mechanism to promote the suppliers' R&D work to improve the whole green supply chain and its own gains. In this study, we discuss the first kind of situations, that is, the incentive mechanism that manufacturers to suppliers to improve the green degree of the intermediate goods by R&D.

Research results for the problem is lacking at present. The related research literature can be divided into two categories. One is the formulation of incentive mechanism between members of the green supply chain. Koplin and Seuring (2007) put forward two incentive mechanism design methods to achieve the sustainable development of the supply chain based on the different social responsibility commitment ways. Wang *et al*. (2009) designed the incentive contracts among the

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remanufacture supply chain members in seven different cases. Combined with Taiwan's electronics industry, Sheu (2011) analyzed the promoting function that several different incentive mechanism modes to the operation of the green supply chain under the government environmental regulation. The other research literature is about the green technology R&D. Du and Cao (2005) pointed out that the continuous technological innovation of the enterprises and products can be implemented according to the 3R principle of the circular economy. Bergek and Jacobsson (2010) based on the empirical analysis found that the implementation of the tradable green certificate could promote the spread of green technology. Pujari (2006) used the hierarchical regression analyses to explore the effect and coordinated relations of the related factors (including the market demand, the technology, the supplier and product life cycle, etc) in the green technology innovation activities. Cantono and Silverberg (2009) put forward the green technology diffusion network model based on the heterogeneity of the consumer preferences. Horwitch and Mulloth (2010) discussed the role and relations of the supply chain members in the process of the green technology innovation and promotion. The above results afford many lessons to this study.

According to a two-echelon supply chain system consists of a manufacturer and a supplier, considering the passivity of the upstream suppliers' technology R&D in the present and under the asymmetric information situation of R&D efforts level and its costs, we designed the incentive mechanisms for suppliers to improve the green degree of intermediate goods. The incentive mechanism can truly reveal the real effort level of the supplier and then promote the rational and efficient operation of the green supply chain. The conclusion of the study has a certain guiding value to the operation of the green supply chain in China today.

DEFINITIONS AND ASSUMPTIONS OF RESEARCH

In order to improve the intermediate green degree *g*, which involved the production process level, green technology level, main components of the intermediate, etc., the supplier should invest the R&D efforts *e* (means the invested money and human that used to improve the green degree of the unit intermediate). So we used g(e) to express the function relation between the intermediate green degree *g* and the R&D efforts *e*. The function g(e) meets the requirement of g (0) = 0, $g' > 0$, $g'' \geq 0$. For simplified analysis, let g(e) = e. That is, if we invest *e* units R&D efforts, the intermediate product can improve the *e* units green degree.

In the green supply chain, we supposed that one unit green product needs one unit green intermediate to process or manufacture. Compared with ordinary products, when one unit intermediate that green degree is g turns into one unit green product by processing or manufacturing, it can increase income R_M for the manufacturer. So we used $R_M(g)$ to express the function relation between the increased income that one unit green product bring to the manufacturer and the green degree g of the intermediate. The function $R_M(g)$ meets the requirement of $R_M(0) = 0$, $R'_M > 0, R'_M > 0$. Let $R_M(g)$ = kg ε+, herein *k* is the unit green degree income coefficient, $k > 0$, ε is the effect that some uncertainty factors (such as the market changes, sales strategy, etc.) to the increased income of one unit green product, $\varepsilon \in N(0, \sigma^2)$.

In order to encourage the R&D of suppliers to improve the intermediate green degree, the manufacturer should give the supplier a linear payment *t* for one unit green product. Let:

$$t = \alpha + \beta R_M = \alpha + \beta\left(ke + \varepsilon\right) \tag{1}$$

where,

α = The fixed payment
β = The linear incentive coefficient

Then, we could get the increased income V_M of the manufacturer's one unit green product:

$$V_M = R_M - t = (1- \beta)\ (ke + \varepsilon) - \alpha \tag{2}$$

Meanwhile, the supplier needs to pay cost to R&D. So we used c(e) to express the effort cost function. The function meets the requirement of c (0) =, $c' > 0, c' \geq 0$. Here let $c(e) = 1/\,2\ be^2$, *b* is the effort cost coefficient of one unit intermediate, b > 0. Then, we could get the increased income V_S of the supplier's one unit intermediate:

$$V_S = t - c\left(e\right) = \alpha + \beta\left(ke + \varepsilon\right) - \frac{1}{2}be^2 \tag{3}$$

Assuming that the manufacturer is risk neutral and then its expectation increased income:

$$EV_M = (1 - \beta)ke - \alpha \tag{4}$$

Considering the risk aversion of the supplier (due to the risk that R&D exists, the supplier would generally adopt the attitude of risk aversion), we could get the supplier's increased income by the certainty equivalent method (Jae, 2000):

$$EV_S = \alpha + \beta ke - \frac{1}{2}be^2 - \frac{1}{2}r\beta^2\sigma^2 \tag{5}$$

where *r* is the risk aversion coefficient of the supplier, r > 0.

In order to improve the green degree of the intermediate products and promote the R&D effort level of the supplier, the incentive mechanism design process of the manufacturer can use the following programming problem:

$$\text{(P)} \max_{\{\alpha,\beta\}} EV_M = (1-\beta)ke - \alpha$$

$$s.t.\ EV_S = \alpha + \beta ke - \frac{1}{2}be^2 - \frac{1}{2}r\beta^2\sigma^2 \geq V_0 \tag{6}$$

$$e \in \arg\max_{\{e\}} EV_S = \alpha + \beta ke - \frac{1}{2}be^2 - \frac{1}{2}r\beta^2\sigma^2 \tag{7}$$

Equation (6) is the Individual Rationality constraint (IR) of the supplier, V_0 is the retention increased income of the supplier. Equation (7) is the Incentive Compatibility constraint (IC) of the supplier.

THE MANUFACTURER COORDINATION MECHANISM DESIGNED UNDER THE SYMMETRIC INFORMATION

In the case of symmetric information, the manufacturer can know the supplier's R&D effort level exactly. Hence Eq. (7) does not work, but any level of effort can be enforced realized by Eq. (6). At the same time, the manufacturer as the client can make the supplier's expectation increased income equals retention increased income V_0. Therefore, the manufacturer's coordination mechanism design could be simplified as the following:

$$\text{(P1)} \max_{\{\alpha,\beta\}} EV_M = (1-\beta)ke - \alpha$$

$$s.t\ EV_S = \alpha + \beta ke - \frac{1}{2}be^2 - \frac{1}{2}r\beta^2\sigma^2 = V_0 \tag{8}$$

From Eq. (8), we can get:

$$\alpha = V_0 + \frac{1}{2}be^2 + \frac{1}{2}r\beta^2\sigma^2 - \beta ke \tag{9}$$

Put Eq. (9) into the target function of (P1), we obtain:

$$EV_M = ke - \frac{1}{2}be^2 - \frac{1}{2}r\beta^2\sigma^2 - V_0 \tag{10}$$

According to the manufacturer's first order condition $\partial V_M / \partial e = 0$ and $\partial V_M / \partial \beta = 0$, we get that:

$$e^* = k/b \tag{11}$$

$$\beta^* = 0 \tag{12}$$

where the superscript * represents the results under asymmetric information. At this point, the Hessian matrix that forms of the second derivative of EV_M is negative. Thus, we could get that:

$$\alpha^* = V_0 + \frac{k^2}{2b} \tag{13}$$

$$c^*(e) = \frac{k^2}{2b} \tag{14}$$

Conclusion 1: In the case of symmetric information, in order to stimulate the most beneficial R&D effort level, the manufacturer could make the fixed payment α equals the supplier's retention increased income V_0 plus the R&D effort cost $c(e)$ and make the linear incentive coefficient β equals 0, that is no reward to pay later.

In addition, we have known that the supplier's expected increased income is $EV^*_s = V_0$. Then we could get the manufacturer's expected increased income and the total expected increased income of both sides:

$$EV_M^* = \frac{k^2}{2b} - V_0 \tag{15}$$

$$EV_T^* = EV_M^* + EV_S^* = \frac{k^2}{2b} \tag{16}$$

Conclusion 2: In the case of symmetric information, both the variables α , β and the supplier's R&D effort level e decided by the risk-neutral manufacturer. Therefore, both the decision variables and the related expected increased income have nothing to do with the supplier's risk aversion degree r and the uncertainty degree σ^2 of income gains. They only related to the unit green degree income coefficient k, R&D effort cost coefficient b and the supplier's retention increased income V_0.

THE MANUFACTURER INCENTIVE MECHANISM DESIGNED UNDER THE ASYMMETRIC INFORMATION

In the case of asymmetric information, the manufacturer couldn't know the supplier's R&D effort level exactly. At this point, the manufacturer's incentive mechanism design problem could be shown as (P). So from Eq.(7) (namely the supplier's incentive compatibility constraint $e \in \arg\max_{\{e\}} EV_S$), we could get the first order condition that could make the supplier's decision-making optimization:

$$\frac{\partial EV_S}{\partial e} = \beta k - be = 0 \tag{17}$$

Then you get:

$$e = \frac{\beta k}{b} \tag{18}$$

Similarly, the manufacturer could make the supplier's (IR) be Eq. (9). Then put Eq. (9) and (18) into the target function (P), we obtain:

$$EV_M = \frac{k^2}{b}\beta - \frac{k}{2b}\beta^2 - \frac{r\sigma^2}{2}\beta^2 - V_0 \tag{19}$$

According to the manufacturer's optimization first order condition $\partial EV_M / \partial\beta = 0$, it is obtained that:

$$\beta^{SB} = \frac{k^2}{k^2 + br\sigma^2} \tag{20}$$

where the superscript *SB* represents the second best result (Laffont, 2002) obtained under the asymmetric information situation. Then combine with Eq.(20), Eq.(18) and Eq.(9), we get:

$$e^{SB} = \frac{k^3}{b\left(k^2 + br\sigma^2\right)} \tag{21}$$

$$\alpha^{SB} = V_0 + \frac{k^4\left(br\sigma^2 - k^2\right)}{2b\left(k^2 + br\sigma^2\right)^2} \tag{22}$$

Conclusion 3: In the case of asymmetric information, the manufacturer's linear incentive coefficient $\beta^{SB}\varepsilon$ (0, 0]. With the increasing of the unit R&D effort cost coefficient *b* and the supplier's risk aversion coefficient *r* and the uncertainty degree σ^2 , the value of β^{SB} will decrease. However, with the increasing of the unit green degree income coefficient *k*, the value of β^{SB} will increase as well. In addition, there is the condition of $\alpha^{SB} < 0$, it could be supposed that the supplier pay the fee to join the green supply chain which led by the manufacturer and engage in the green technology R&D.

In addition, the manufacturer also could make the supplier's expected increased income $EV^{SB}_S = V_0$ under the asymmetric information situation. Then we obtain:

$$EV_M^{SB} = \frac{k^4}{2b\left(k^2 + br\sigma^2\right)} - V_0 \tag{23}$$

$$EV_T^{SB} = EV_M^{SB} + EV_S^{SB} = \frac{k^4}{2b\left(k^2 + br\sigma^2\right)} \tag{24}$$

Conclusion 4: In the case of asymmetric information, with the increasing of the unit R&D effort cost coefficient *b*, the supplier's risk aversion coefficient *r* and the uncertainty degree σ^2, both the manufacturer's expected income EV^{SB}_M and the total expected income EV^{SB}_T will decrease. However, with the increasing of the unit green degree income coefficient *k*, both will increase.

COMPARISON OF THE TWO MECHANISMS AND THE MAIN CONCLUSIONS

Compare the coordination mechanism under the symmetric information situation with the manufacturer's incentive mechanism under the asymmetric information situation. We could get that:

$$\beta^{SB} = \frac{k^2}{k^2 + br\sigma^2} > \beta^* = 0 \tag{25}$$

$$\frac{e^{SB}}{e^*} = \beta^{SB} = \frac{k^2}{k^2 + br\sigma^2} < 1 \tag{26}$$

Notice $k^2(br\sigma^2 - k^2)/(k^2 + br\sigma^2)^2 < 1$, thus $\alpha^{SB} < \alpha^*$. Furthermore, because of $EV^{SB}_S = EV^{SB}_S = V_0$, then we get $EV^{SB}_M < EV^*_M$ and:

$$\frac{EV_T^{SB}}{EV_T^*} = \beta^{SB} = \frac{k^2}{k^2 + br\sigma^2} < 1 \tag{27}$$

Conclusion 5: Due to the existence of asymmetric information, the suppliers' R&D effort level will drop. The manufacturers' income and the green supply chain's total income will decrease as well. However, the complete information sharing will lead to the improvement of the supplier's R&D effort level while the income does not increase. In the actual operation of green supply chain, it is difficult to eliminate information asymmetry phenomenon due to the individual rationality of each member. Although the above-mentioned contract { α^{SB} , β^{SB} }is hard to make the cooperation efficiency achieve the Pareto optimality, it is already the best incentive mechanism to stimulate the supplier's largest R&D effort level under the realistic conditions.

CONCLUSION

Members of the green supply chain faced all kinds of moral hazard problems in the process of collaborative transactions. The existence of asymmetric information reduced the realization of a more-efficient trade and cooperation among members, reduced the effort effect of the resources optimal allocation of the green supply chain, reduced the company members' and the green supply chain's total income and then reduced the competitiveness of the green supply chain in the product market. In this study, according to a two-echelon supply chain system consists of a manufacturer and a supplier, we discussed the manufacturer's incentive mechanism design problem by linear sharecropping to promote the upstream suppliers' R&D work which can improve the green degree of the intermediate products and compared the coordination mechanism under the symmetric information situation with the incentive mechanism under the asymmetric information situation of the manufacturer. The proposed incentive mechanisms can stimulate the supplier's R&D efforts level at its maximum and make the income maximization goal achieved as far as possible. This study has a certain practical guiding significance to the related decisions about the green technology R&D of members of the green supply chain in the early green market.

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