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Partner Selection Mechanism of Cooperative Innovation in Project-based Supply Chain Based on the Effect of Knowledge Level

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Abstract

The knowledge level of partners is an important index for dominant enterprise of cooperative innovation project to select partner in project-based supply chain. Aiming at the adverse selection problem under the knowledge level of partners can't observe in advance, the partner selection mechanism of cooperative innovation in project-based supply chain is designed with principal-agent theory. The conclusions indicate that the dominant enterprise selects an appropriate partner mainly based on its knowledge level and cost of cooperative innovation; the reward of partner from the dominant enterprise is mainly composed of cost of knowledge input and information rent; and the knowledge level of partner to be selected by dominant enterprise under adverse selection is lower than that under complete information.

Key words

Partner Selection, Cooperative Innovation, Project-based Supply Chain, Knowledge Level

1. Introduction

Over the last few decades, scholars are dedicating an increasing amount of their research

efforts to the relation between knowledge management and innovation [1]. The knowledge necessary for corporate innovation activities is, however, more complex, and even large-scale firms face shortages of knowledge. Given their scarce resources, firms attempt to cooperate with other firms to acquire knowledge and resources, and engage in cross-organizational knowledge sharing to enhance innovation performance [2]. Based on the different and complementary knowledge resources between members in supply chain, cross-organizational knowledge sharing has become an important strategy for the members to create new value, save the cost of innovation and exploit depth profit by cooperative innovation in supply chain [3]. In these circumstances, the idea of project management is introduced into the supply chain management, and the concept of project-based supply chain is defined. The cooperative innovation of project-based supply chain is a management mode where all project participators organized by the cooperation contract to balance interests of all parties, identify project objectives, establish perfect coordination and communication mechanisms and finally realize reasonable risk-sharing and amicable settlement of disputes [4]. In this mode, members with different and complementary core knowledge usually establish and disband in terms of supply chain as projects proceed. These members form the project-based organizations of supply chain and play different roles in supply chain inter-organizational cooperative innovation.

As the original drive for innovation, knowledge is an essential factor in maintaining core competence of project-based supply chain, which cannot be replaced in the appreciation of project value [5]. Therefore, the success of the innovation or the degree of innovation often depends on the quantity and quality of knowledge, namely knowledge level of members in supply chain is the most critical factor of the cooperative innovation projects [6]. However, the characteristics of knowledge (especially the tacit knowledge) are intangible, difficult to measure and external, the dominant enterprises of cooperative innovation in project-based supply chain are often difficult to observe the real level of knowledge of potential partners in advance. If the selected partners have lower knowledge level or cannot match with the knowledge of the dominant enterprises that will significantly reduce the success probability of cooperative innovative projects. Therefore, the imperative problem now is how to design the partner selection mechanism of cooperative innovation in project-based supply chain. At present, there is a number of literatures focused on

problems of cooperative innovation in project-based supply chain. These studies mainly focus on problem that is how to establish the knowledge collaborative incentive mechanisms (the perspective of effort level of partners, equity preference, pay costs, distribution coefficient, mutual preference, etc) among project-based members after the agreement of cooperative innovation has been reached [7-10]. However, the critical problem of partner selection (about knowledge level) has not yet been studied before the agreement of cooperative innovation has been reached, and the knowledge level of partners is an important index for dominant enterprise of cooperative innovation to select cooperative partner in project-based supply chain.

In view of this, aiming at the adverse selection problem under the knowledge level of partners can't observe in advance, this paper intends to introduce the principal-agent theory to design partner selection mechanism of cooperative innovation in project-based supply chain in order to incentive partners to show their the true knowledge level. The results of the study can provide theoretical support for dominant enterprise of cooperative innovation to select the most suitable cooperative partner in project-based supply chain.

2. The Problem Description and Model Assumptions

In the project-based supply chain, manufacturer as the core enterprise is risk neutral, which is the dominant enterprise of cooperative innovation project need the suppliers to participate and provide the corresponding knowledge support. The number of suppliers is n and all of the suppliers are risk neutral in supply chain. In addition, knowledge level is considered as the most critical indicator when manufacturer selects suppliers. In this study, the knowledge level is a comprehensive index, which is mainly manifested in the stock on knowledge production elements represented by knowledge, technology and human resources. In the process of cooperative innovation, the manufacturer is difficult to observe real knowledge level of suppliers before the agreement of cooperative innovation has been reached due to the unique attributes of knowledge. Therefore, the suppliers have the issues that knowledge level their declared may deviate from their true knowledge level. In this situation, manufacturer is likely to get low level of knowledge or the knowledge does not match the cooperative innovation at higher cost that may reduce the success probability of cooperative innovative project.

In view of the above adverse selection problem, this paper will design the partner selection mechanism to ensure dominant enterprise (manufacturer) in project-based supply chain to select the most suitable partner (supplier) on the cooperative innovative project. The specific mechanism design for partner selection can be divided into the following four stages:

(1) As the dominant enterprise of cooperative innovation project, the bidding information of cooperative innovation project for potential suppliers (n is the number of suppliers) in the supply chain is released by manufacturer.

(2) Potential supplier i ($i=1,2,\cdots n$) in supply chain will participate in project bidding by contract with combination (r_i,k_i) of participation reward r_i and knowledge level k_i when the expected return is greater than 0.

(3) Manufacturer decides whether the supplier i gets the cooperation opportunities or not according to the combination (r_i,k_i), which is expressed by 0-1 decision variable $p_i(r,k)$. To any supplier, both cases that losing or getting the contract are possible, it is $p_i(r,k)=1$ or $p_i(r,k)=0$, $r=(r_1,r_2,\cdots r_n)$ is the vector consisting of participation reward for the suppliers offered, $k=(k_1,k_2,\cdots k_n)$ is the vector consisting of knowledge level claimed by each supplier.

(4) Manufacturer can design partner selection contract which include contract selection and final payment of reward according to display principle [11], which is represented by the contract menu $(p_i(r,k),t_i(r,k))$. In the contract menu, $t_i(r,k)$ implies the final payment that manufacturer paid to the supplier.

In order to facilitate the establishment of model for quantitative analysis, we first make the following assumptions:

Assumption 1: The cost function of knowledge input for suppliers to participate in the cooperative innovation project is $c(k)$, $c'(k)>0$, $c''(k)>0$. The cooperative innovation income of manufacturer is $V(k)$, $V'(k)>0$, $V''(k)\le 0$.

Assumption 2: Manufacturer and supplier understand structural parameters of the cost function of knowledge input, namely the cost function $c(k)$ is the common information. The

knowledge level of the supplier is personal information, manufacturer and other suppliers only know random distribution of the knowledge level, that is $k_i \in [\underline{k}, \overline{k}]$. Moreover, we assume that random distribution function of knowledge level is $F(\cdot)$, density is $f(\cdot)$ and $\frac{F(\cdot)}{f(\cdot)}$ meets no decreasing.

Assumption 3: As the dominant enterprise of cooperative innovation project, the manufacturer has full bargaining power and the right to decide whether supplier i can get contract or not according to combination (r_i, k_i) of reward r_i and knowledge level k_i that the supplier i submitted.

3. Partner Selection Model of Cooperative Innovation in Project-based Supply Chain

According to the decision variables $p_i(r,k)$, if the supplier i gets the cooperative innovation contract from the manufacturer , the expected return it received from the manufacturer is $t_i(r,k)$, and the net income of manufacturer through the cooperative innovation project is $V(k_i) - t_i(r,k)$, and $t_i(r,k) = r_i p_i(r,k)$.

As manufacturer and supplier are risk-neutral, so the expected return is equivalent to expected utility [12], the expected return Π of manufacturer can be expressed as:

$$\Pi = E_k \sum_{i=1}^{n} [p_i(r,k)V(k_i) - t_i(r,k)] = E_k \sum_{i=1}^{n} p_i(r,k)[V(k_i) - r_i] \quad (1)$$

When the supplier i bids by the real knowledge level k_i, the expected return $U_i(r_i, k_i)$ can be expressed as:

$$U_i(r_i, k_i) = E_{k_{-i}}[t_i(r,k) - p_i(r,k)c(k_i)] = E_{k_{-i}}[p_i(r,k)(r_i - c(k_i))] \quad (2)$$

When the real knowledge level of the supplier is k_i, but it bids at the knowledge level of $\hat{k}_i$, the expected return $U_i(r_i,\hat{k}_i,k_i)$ can be expressed as:

$$U_i(r_i,\hat{k}_i,k_i)=E_{k_{-i}}[t_i(r,\hat{k}_i,k_{-i})-p_i(r,\hat{k}_i,k_{-i})c(k_i)]=E_{k_{-i}}[p_i(r,\hat{k}_i,k_{-i})(r_i-c(k_i))] \tag{3}$$

In the equations (2) and (3), $k_{-i}=\{k_1,\cdots k_{i-1},k_{i+1},\cdots k_n\}$ is the vector consisting of knowledge level of suppliers except supplier i; $t_i(r,\hat{k}_i,k_{-i})=r_i p_i(r,\hat{k}_i,k_{-i})$ represents the expected return obtained by supplier i at knowledge level $\hat{k}_i$ when the actual knowledge level is k_i; $p_i(r,\hat{k}_i,k_{-i})$ represents the contract decisions that the knowledge level of supplier i claimed is $\hat{k}_i$ when the actual knowledge level is k_i with the participation reward is r_i.

As the dominant enterprise of cooperative innovation project, the issue of manufacturer is that how to reduce the adverse effects resulted from the information disadvantage through effective mechanisms design. In asymmetric information, the manufacturer will design partner selection contract for the aim at their own maximum income and the contract they provide must meet two conditions: participation constraints and incentive compatibility constraints. The contract can be summarized as the principal-agent model P1:

$$\textbf{P1}\quad \max_{p_i(r,k),t_i(r,k)}\Pi=E_k\sum_{i=1}^{n}p_i(r,k)[V(k_i)-r_i] \tag{4}$$

$$\text{S.t.}\quad \text{(IR)}\quad E_{k_{-i}}[p_i(r,k)(r_i-c(k_i))]\geq 0 \qquad \forall k_i\in[\underline{k},\overline{k}] \tag{5}$$

$$\text{(IC)}\quad E_{k_{-i}}[p_i(r,k_i,k_{-i})(r_i-c(k_i))]\geq E_{k_{-i}}[p_i(r,\hat{k}_i,k_{-i})(r_i-c(k_i))] \qquad \forall k_i\in[\underline{k},\overline{k}] \tag{6}$$

$$r_i\in\arg\max_{r_i}E_{k_{-i}}[p_i(r,k)(r_i-c(k_i))] \qquad \forall k_i\in[\underline{k},\overline{k}] \tag{7}$$

$$p_i(r,k) \in \{0,1\} \qquad \forall k_i \in [\underline{k}, \overline{k}] \tag{8}$$

$$\sum_{i=1}^{n} p_i(r,k) = 1 \qquad \forall k_i \in [\underline{k}, \overline{k}] \tag{9}$$

In above model, $p_i(r,k_i,k_{-i})$ represents the contract decision when the actual knowledge level of supplier i is k_i and participation reward is r_i; $p_i(r,\hat{k}_i,k_{-i})$ represents the contract decision that the knowledge level of supplier i claimed is $\hat{k}_i$ when the actual knowledge level is k_i with the participation reward is r_i. In addition, the formula (4) is objective function of manufacturer, $p_i(r,k)$ and $t_i(r,k)$ respectively indicates the contract decisions and expected payment based on maximizing their own earnings. Formula (5) represents the participation constraints for supplier. Formula (6) is the incentive compatibility constraints. Formula (7) represents decision-making of supplier i for the aim at maximizing its expected return . Formula (8) represents that $p_i(r,k)$ is decision variables which can only be 0 or 1. Formula (9) indicates that the manufacturer can select partner from n suppliers to participate in the cooperative innovation project.

4. The Model Solution and the Optimal Contract Mechanism Analysis

The game between manufacturer and supplier is the two-stage. In the first stage, supplier i bids according to combination (r_i,k_i) of reward r_i and knowledge level k_i. In the second stage, manufacturer selects the most suitable supplier as cooperative innovation partner according to the knowledge level vector $k=(k_1,k_2,\cdots k_n)$ and participation reward vector $r=(r_1,r_2,\cdots r_n)$ of suppliers. The adverse selection model of above-mentioned can be solved reversely in accordance with stackelberg game. That is, r and k is firstly given, the decision of manufacturer is based on the variables $p(r,k)$; and then the optimal decision of participation reward r^* is made by supplier

on the basis of given $p(r,k)$.

For the formula (5), when the supplier i claims to the manufacturer that it has the highest knowledge level is $\overline{k}$, based on the assumption 1: $c(k_i) \le c(\overline{k})$, the inequality $E_{k_{-i}}[t_i(r,\overline{k},k_{-i}) - p_i(r,\overline{k},k_{-i})c(k_i)] > E_{k_{-i}}[t_i(r,\overline{k},k_{-i}) - p_i(r,\overline{k},k_{-i})c(\overline{k})]$ is established.

If the formula (6) is established, the inequality:

$E_{k_{-i}}[t_i(r,k_i,k_{-i}) - p_i(r,k_i,k_{-i})c(k_i)] > E_{k_{-i}}[t_i(r,\overline{k},k_{-i}) - p_i(r,\overline{k},k_{-i})c(k_i)]$ is established.

When formula (6) is established, $E_{k_{-i}}[t_i(r,\overline{k},k_{-i}) - p_i(r,\overline{k},k_{-i})c_i(\overline{k})] \ge 0$ can guarantee that any $k_i \in [\underline{k},\overline{k}]$ makes formula (5) established.

Manufacturer in the formula (5) generally does not make incentives for suppliers, that is, manufacturer could adopt tight constraint on the participation constraint, and namely participation constraint formula (5) is equivalent to:

$$U_i(r_i,\overline{k}) = 0 \tag{10}$$

Formula (10) means that if they can guarantee the suppliers with the highest knowledge level $\overline{k}$ to participate in cooperative innovation project, they will also be able to ensure all types of suppliers to participate in such projects.

The second stage of the game is to determine the decision variables $p(r,k)$ in optimal selection mechanism, and thus they can make optimal contract menu $(p_i(r,k),t_i(r,k))$ for partner selection in innovative cooperation project.

After solving the model P1, we analyze relevant properties of the optimal partner selection contract, the following proposition is obtained:

Proposition 1: When the knowledge level of suppliers cannot be observed in advance, the principle for manufacturer to select partner is: if $V(k_i) - B(k_i) > V(k_j) - B(k_j), i \ne j$, supplier i

will get the contract, at the time, $p_i(r,k)=1$; if $V(k_i)-B(k_i)<V(k_j)-B(k_j), i\neq j$, the supplier i will not get the contract, at the time, $p_i(r,k)=0$. In above formulas, there are $B(k_i)=c(k_i)+c'(k_i)\frac{F(k_i)}{f(k_i)}$ and $B(k_j)=c(k_j)+c'(k_j)\frac{F(k_j)}{f(k_j)}$.

Prove:

It can be obtained by the formula (2):

$$E_{k_{-i}}[t_i(r,k)]=U_i(r_i,k_i)+E_{k_{-i}}[p_i(r,k)c(k_i)] \tag{11}$$

Then:

$$E_k[t_i(r,k)]=\int_{\underline{k}}^{\bar{k}}U_i(r_i,k_i)f(k_i)dk_i+E_k[p_i(r,k)c(k_i)] \tag{12}$$

According to the formula (12), the expected revenue of manufacturer formula (1) can be expressed as:

$$\Pi=E_k\sum_{i=1}^{n}p_i(r,k)[V(k_i)-c(k_i)]-\sum_{i=1}^{n}\int_{\underline{k}}^{\bar{k}}U_i(r_i,k_i)f(k_i)dk_i \tag{13}$$

We can know from formula (2) according to the envelope theorem that:

$$\begin{aligned}&\frac{dU_i(r_i,k_i)}{dk_i}=-E_{k_{-i}}[p_i(r,k)c'(k_i)]\\&U_i(r_i,k_i)=U_i(r_i,\bar{k})+\int_{k_i}^{\bar{k}}E_{k_{-i}}[p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)]d\tilde{k}_i\end{aligned} \tag{14}$$

It can be obtained from the formula (14):

$$\int_{\underline{k}}^{\bar{k}} U_i(r_i,k_i)f(k_i)dk_i = U_i(r_i,\bar{k}) + \int_{\underline{k}}^{\bar{k}}\int_{k_i}^{\bar{k}} E_{k_{-i}} p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)d\tilde{k}_i f(k_i)dk_i$$
$$= U_i(r_i,\bar{k}) + [F(k_i)\int_{k_i}^{\bar{k}} E_{k_{-i}} p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)d\tilde{k}_i]_{\underline{k}}^{\bar{k}} + \int_{\underline{k}}^{\bar{k}} E_{k_{-i}} p_i(r,k_i,k_{-i})c'(k_i)F(k_i)dk_i \quad (15)$$
$$= U_i(r_i,\bar{k}) + E_k[p_i(r,k_i,k_{-i})c'(k_i)\frac{F(k_i)}{f(k_i)}]$$

Substituting (15) into equation (13), we can obtain:

$$\Pi = E_k \sum_i p_i(r,k)[V(k_i) - c(k_i) - c'(k_i)\frac{F(k_i)}{f(k_i)}] - \sum_i U_i(r_i,\bar{k}) \quad (16)$$

Let $B(k_i) = c(k_i) + c'(k_i)\frac{F(k_i)}{f(k_i)}$ (17)

The formula (10) shows that $U_i(r_i,\bar{k}) = 0$, so the formula (16) can be converted to:

$$\Pi = E_k \sum_i p_i(r,k)[V(k_i) - B(k_i)] \quad (18)$$

As manufacturer selects suppliers to participate in cooperative innovation project for the aim at maximizing the expected income, namely maximizing $V(k_i) - B(k_i)$. So for supplier i, as long as $V(k_i) - B(k_i) > V(k_j) - B(k_j)$ is existing, $i \neq j$, manufacturer will be sure to select supplier i to participate in cooperative innovation, namely $p_i(r,k) = 1$. When $V(k_i) - B(k_i) < V(k_j) - B(k_j)$, $i \neq j$, manufacturer will not select supplier i to participate in cooperative innovation, namely $p_i(r,k) = 0$.

In summary, the proposition 1 has been proved.

Proposition 2: When the knowledge level of supplier cannot be observed in advance, in the optimal partner's selection contract, the reward from the manufacturer to the supplier i can be expressed as:

$$t_i(r,k)=\begin{cases} c(B^{-1}(V(k_i)-V(k_\lambda)+B(k_\lambda)))-c(k_i), & if: p_i(r,\tilde{k}_i,k_{-i})=1 \\ 0, & if: p_i(r,\tilde{k}_i,k_{-i})=0 \end{cases}$$

And $V(k_\lambda)-B(k_\lambda)=\max_{j\neq i}V(k_j)-B(k_j)$.

Prove:

We can know that from formula (14) and $U_i(r_i,\bar{k})=0$:

$U_i(r_i,k_i)=\int_{k_i}^{\bar{k}}E_{k_{-i}}[p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)]d\tilde{k}_i$, and the formula (2) shows that:

$$U_i(r_i,k_i)=E_{k_{-i}}[t_i(r,k)-p_i(r,k)c(k_i)]=E_{k_{-i}}\int_{k_i}^{\bar{k}}[p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)]d\tilde{k}_i \quad (19)$$

Therefore, the reward from the manufacturer to the supplier i is:

$$t_i(r,k)=p_i(r,k)c(k_i)]+\int_{k_i}^{\bar{k}}[p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)]d\tilde{k}_i \quad (20)$$

Let $V(k_\lambda)-B(k_\lambda)=\max_{j\neq i}V(k_j)-B(k_j)$

By Proposition 1, the condition of the supplier i getting the contract can be written as $V(k_i)-B(k_i)>V(k_\lambda)-B(k_\lambda)$, namely:

$$V(k_i)-V(k_\lambda)+B(k_\lambda)>B(k_i) \quad (21)$$

Because of $B(k_i)=c(k_i)+c'(k_i)\frac{F(k_i)}{f(k_i)}$ and $B'(k_i)>0$, the condition formula (21) of the supplier i getting the contract can be rewritten as:

$k<B^{-1}(V(k_i)-V(k_\lambda)+B(k_\lambda))$

Noting $z_i(k_{-i})$ as the maximum knowledge level in k_i that supplier i can get the contract.

So $z_i(k_{-i})=\{\sup k_i \,|\, V(k_i)-B(k_i)>V(k_j)-B(k_j)\}=\{\inf k_i \,|\, B^{-1}(V(k_i)-V(k_\lambda)+B(k_\lambda))\}$

If $\underline{k}<z_i(k_{-i})<\bar{k}$, there are:

① when $\tilde{k}_i > z_i(k_{-i})$, $p_i(r,k)$=0, $t_i(r,k)=0$

So $t_i(r,k)=c(k_i)+c(B^{-1}(V(k_i)-V(k_\lambda)+B(k_\lambda)))$

It means that participation reward from the manufacturer to suppliers is composed of knowledge input cost and information rent which derived from the asymmetric information.

② when $\underline{k} < \tilde{k}_i < z_i(k_{-i})$, $p_i(r,k)$=1

So, $\int_{k_i}^{\bar{k}}[p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)]d\tilde{k}_i$ in the formula（19）can be written as:

$$\int_{k_i}^{\bar{k}}[p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)]d\tilde{k}_i=\int_{k_i}^{z_i(k_{-i})}[p_i(r,\tilde{k}_i,k_{-i})c'(\tilde{k}_i)]d\tilde{k}_i=c(z_i(k_i))-c(k_i)$$

In summary, the proposition 2 has been proved.

Proposition 3: In the case of asymmetric information, the knowledge level required to have when the supplier gets the contract is not higher than that under the case of complete information in the optimal partner selection contract.

Prove:

In the case of complete information, the manufacturer fully understands the knowledge level of supplier i, the participation reward in the decision model only needs to ensure the participation of suppliers i, and the incentive compatibility constraint does not exist. The problem of manufacturer under complete information can be expressed as model P2:

$$\textbf{P2}\quad \max_{p_i(r,k),t_i(r,k)} \Pi(p_i,t_i)=\sum_i[p_i(r,k)V(k_i)-t_i(r,k)] \tag{22}$$

$$\textbf{S.t.}\quad U_i(r_i,k_i)=0 \qquad \forall k_i\in[\underline{k},\bar{k}] \tag{23}$$

$$p_i(r,k)\in\{0,1\} \qquad \forall k_i\in[\underline{k},\bar{k}] \tag{24}$$

$$\sum_{i=1}^{n}p_i(r,k)=1 \qquad \forall k_i\in[\underline{k},\bar{k}] \tag{25}$$

It can be obtained from constraints (23) and $U_i(r_i,k_i)=t_i(r,k)-p_i(r,k)c(k_i)=0$ that:

$$t_i(r,k)=p_i(r,k)c(\mu_i) \tag{26}$$

Substituting formula (26) into equation (22), we can obtain:

$$\max_{p_i(r,k)} \Pi(p_i,t_i)=\sum_i \{p_i(r,k)[V(k_i)-c(k_i)]\} \tag{27}$$

So, we can know from above mention that under complete information, the condition of supplier i getting the contract is: when $V(k_i)-c(k_i)>V(k_j)-c(k_j)$, supplier i will be selected, that is $p_i(r,k)$=1. At this time, the knowledge level required to have when supplier i gets the contract can be decided by the following model P3:

P3 $\max_{k_i} V(k_i)-c(k_i)$ (28)

S.t. First order condition: $V'(k_i)-c'(k_i)=0$ (29)

Second order condition: $V''(k_i)-c''(k_i)<0$ (30)

In the case of asymmetric information, according to proposition 1, the condition of supplier i getting the contract is $V(k_i)-B_i(k_i)>V(k_j)-B_j(k_j)$, besides, with $B_i(k_i)=c(k_i)+c'(k_i)\frac{F(k_i)}{f(k_i)}$ and $w(k_i)=c'(k_i)\frac{F(k_i)}{f(k_i)}$, so the knowledge level of supplier i to get contract can be represented by the model P4:

P4 $\max_{k_i} V(k_i) - c(k_i) - c'(k_i)\frac{F(k_i)}{f(k_i)}$ (31)

S.t. First order condition: $V'(k_i) - c'(k_i) - w'(k_i) = 0$ (32)

Second order condition: $V''(k_i) - c''(k_i) - w''(k_i) < 0$ (33)

Let $L(k_i) = V'(k_i) - c'(k_i) - w'(k_i)$, $L'(k_i) = V''(k_i) - c''(k_i) - w''(k_i)$. It assumed that the optimal knowledge level is k_i^* when supplier i gets the contract in the case of complete information and the optimal knowledge level is k_i^{**} of supplier i claimed in the case of asymmetric information. Then, substituting k_i^* and k_i^{**} into equation $L(k_i)$, we can obtain:

$$L(k_i^*) = V'(k_i^*) - c'(k_i^*) - w'(k_i^*) \quad (34)$$

$$L(k_i^{**}) = V'(k_i^{**}) - c'(k_i^{**}) - w'(k_i^{**}) = 0 \quad (35)$$

Also $w(k_i) = c'(k_i)\frac{F(k_i)}{f(k_i)}$, $w'(k_i) = c''(k_i)\frac{F(k_i)}{f(k_i)} + c'(k_i)\frac{d\frac{F(k_i)}{f(k_i)}}{dk_i}$, so $w'(k_i) > 0$.

We can know $L(k_i^*) < 0$ from formula (29) and formula (34), and combining (35), we can obtain: $L(k_i^{**}) > L(k_i^*)$.

We can know $L'(k_i) < 0$ from formula (33), and then we can obtain $k_i^* \geq k_i^{**}$. That is, in the case of asymmetric information, the knowledge level required to have when the supplier gets the contract is not higher than that under the case of complete information in the optimal partner selection contract.

In summary, the proposition 3 has been proved.

5. Discussion

Aiming at the adverse selection problem under the knowledge level of partners can't observe in advance, the partner selection mechanism of cooperative innovation in project-based supply chain has been designed with principal-agent theory in this paper. The discussions of this study are as follows through the model solution and analysis.

(1) Manufacturer as the dominant enterprise of cooperative innovation project can obtain maximum income through the the optimal partner selection contract of cooperative innovation project when the knowledge level of supplier i meets $V(k_i)-B_i(k_i)>V(k_j)-B_j(k_j)$, that is the supplier i will be selected by manufacturer. The participation reward of suppliers do not affect the partner selection of manufacturer, suppliers get contract mainly through competition between the knowledge level.

(2) We can show that the suppliers with the high knowledge level do not necessarily get the contract of cooperative innovation. The reason is that the reward from the manufacturer to the suppliers is composed of knowledge input cost and information rent, the higher knowledge level means higher quantity and quality inputs of knowledge, correspondingly, knowledge input cost is higher, thereby manufacturer will pay a high cost of cooperative innovation when select suppliers to participate in cooperative innovation project. Therefore, manufacturer should consider its expected income, the knowledge level of suppliers and the cost of innovative cooperation when select suppliers rather than blindly select the suppliers with high knowledge level as a partner.

(3) If knowledge level cannot be observed in advance, it will make the knowledge level required to have when the suppliers get the contract is not higher than the case of complete information, which is conducive to suppliers with low knowledge level to participate competition. Thus, under the circumstances of information asymmetry, it reduces the threshold of enterprises to participate in cooperative innovation, so that the cooperative innovation between enterprises is more active in project-based supply chain.

6. Conclusions and limitations

In project-based supply chain, cross-organizational cooperative innovation is actually the interplay among project-based organizations, the core of which is the cross-organizational knowledge flow and transmission, laying the foundation for the achievement of cross-organizational interplay, cooperative innovation and project value-adding. The success of the cross-organizational cooperative innovation projects often depends on the quantity and quality of knowledge, namely knowledge level of partners in project-based supply chain is the most critical factor of the cooperative innovation projects. Therefore, the knowledge level of partners is an important index for dominant enterprise of cooperative innovation project to select partner in project-based supply chain. Aiming at the adverse selection problem under the knowledge level of partners can't observe in advance, the partner selection mechanism of cooperative innovation in project-based supply chain is designed with principal-agent theory. The conclusions indicate that the dominant enterprise selects an appropriate partner mainly based on its knowledge level and cost of cooperative innovation; the reward of partner from the dominant enterprise is mainly composed of cost of knowledge input and information rent; and the knowledge level of partner to be selected by dominant enterprise under adverse selection is lower than that under complete information.

In addition, the problem of this paper had been studied based on the background of adverse selection (that is the information asymmetry before the cooperative innovation agreement has been reached), and we assume the participants of cooperative innovation will fulfill the agreement conscientiously. In the future, we can research the problems of cooperative innovation in project-based supply chain based on the background of moral hazard, double-sided moral hazard, or the coexistence of adverse selection and moral hazard.

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