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Research on benefit distribution of the equilibrium about R&D network cooperation

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ABSTRACT

Study the impact of benefit distribution on the equilibrium of R&D network cooperation, and find that if we introduce a mechanism of benefit transfer, the condition that make the n enterprises' cooperation to become a Nash equilibrium will be loosen, which means that the mechanism of benefit transfer makes the cooperation become a Nash equilibrium in a wider range of circumstances. Know the mechanism of benefit transfer is conducive to formation of R&D network. Furthermore, study the feasible region and equilibrium solution of transfer coefficient, and get the equilibrium solution under the condition of individual optimum as well as the overall optimum.

Keywords: R&D network; Mechanism of benefit distribution; Benefit transfer

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INTRODUCTION

With the development of globalization, informationization and networking of world economy, technical innovation also has the trend of globalization, informationization and networking. R&D network is a cooperation mode in the circumstance. In the paper, R&D network refers to the union of enterprises, universities and research institutions while they are in research process. R&D network is also a strategic alliance of globalization, informationization and networking, which is different from common innovation strategy alliance, because the participants in R&D networks have great otherness in their resource and ability. Besides, they form open network partnership based information network. Be faced with complex innovation environment, more and more enterprises adopt open innovation mode in network research and innovation. Li, Kozhikode and Boutellier, Gassmann, Zedtwitz [2,10] find that R&D network has been the superior character of innovation environment.

The R&D network can enhance the innovation specificity. For example, it can lower the R&D risk of enterprises, be quick response to the needs of customers abroad, help enterprises get excess benefit and economies of scale [3]. Besides, enterprises can get further ability for performance through innovation in R&D networks [4]. Spencer [5] finds that the innovation performance of enterprises shared technical knowledge with international innovation systems is higher than with internal innovation systems. Li, Kozhikode, Boutellier, Gassmann and Zedtwitz [1-2] think that many transnational enterprises prefer to locate their R&D center in the emerging countries including China.

The research of R&D networks attracts many internal or international scholars. With the development of integration, modularization, networks, the activities of innovation become more and more complex. Rothwell [6] think that people's understanding of technical innovation mechanism begins from simple linear models to complex interaction models. Iansiti [7] generally defines technique integration as the investigation, evaluation and improvement based on the matching of innovation techniques' choices and of techniques application background. The essence is to integrate the value chain of industry technique innovation.

In network models, Almirall and Casadesus-Masanell [8] advance four open innovation network models, which establishes good theory basis of R&D networks' further research. About the motives of R&D network's form, scholars have studied from some aspects such as resource sharing and benefits distribution. McDonough, Athanassion, and Barczak [9] think that international networks will provide more source of innovation.

The researches on the types and measures of R&D network are mainly on the basis of analysis of organization theory, social network theory and transaction costs theory. To analyze in organization theory, the network organizations are open type, enclosed type, close type and loose type [10]. Enkel [11] explores the open R&D and innovation. From the perspective of social network theory, the researches focus mainly on the structure and relations characters of R&D network. The characters of R&D network include centrad, pluralism, structural holes and direct & indirect relation [12]. And the relation characters mainly include relation intensity, close degree and relation trust [13-14].

The R&D network can not always attain the final equilibrium. T. K. and Teng B.S. [15] summarize the instability of strategy alliance from the point of view of trade costs, resource dependency and consignation-agent problems. In which conditions the R&D networks can attain the final cooperation equilibrium is what the academic community is always exploring.

In the paper, we introduce a mechanism of benefit transfer and discuss its impact on the equilibrium of R&D Network Cooperation. Mechanism of benefit transfer is a zero-sum benefit transfer. Its essence is transferring the profit of some participants to others while the sum of profit remains the same. By introducing the mechanism of benefit transfer, participants who have great output ability will get some further compensation. This will strengthen their cooperation ability and fix the cooperation relationship.

2. R&D network game models in simple distribution mode

The simplest mode of R&D Network participants' benefit distribution based on input scale. First, the paper discusses the game equilibrium in the simple distribution mode. Then we introduce the mechanism of benefit transfer and discuss its impact on the equilibrium of R&D Network Cooperation.

Considering a research group which consists of finite enterprises, we regard them and their relationship as networks [16]. And these enterprises are the nodes of the network. The set of all nodes is denoted by N, $N=\{1,2,...,n\}$, n is the number of enterprises. The technical abilities of each enterprise are not totally same. As they have some complements, there exit potential cooperation opportunities to form R&D network for technique development together. Every enterprise faces two game strategies: research alone or research together by join in R&D network.

If each enterprise chooses R&D alone, the ith enterprise's R&D input is denoted by I_i, and R&D benefit is denoted by P_i, so net benefit is $R_i = P_i - I_i$. And if these n enterprises constitute a R&D Network in which they mutually cooperate, share their resource and invest R&D together for knowledge complementarity, they better the condition of input and output. We denote the R&D input of these n enterprises' network as $I = \sum_{i=1}^{n} I_i$, the whole R&D benefit as P, so the whole net R&D benefit is $R = P - I$. Denote the ith enterprise's input scale as $\lambda_i = I_i / I$, and the net benefit of the ith enterprise in simple distribution mode by $\lambda_i R = \lambda_i P - I_i$, and meet the condition $\sum_{i=1}^{n} \lambda_i = 1,\ \lambda_i \geq 0$.

Assume net benefit is the only factor which enterprises consider during R&D decision. In order to let each enterprise join the R&D networks for R&D activities together, the requirement of the cooperation of n enterprises is as follows:

$$\lambda_i R \geq R_i,\ \forall i = 1,2,...,n \tag{1}$$

Under the inequalities condition (1), each enterprise doing R&D activities in the R&D network will get higher benefit than alone. So they are unwilling to escape the R&D network. As defined by the Nash equilibrium, joining R&D networks is a Nash equilibrium of enterprise game. We call the inequalities condition (1) "micro conditions", because it is decision-making basis of a single enterprise. And the following is an unnecessary and sufficient condition different from the inequalities condition:

$$R \geq \sum_{i=1}^{n} R_i \tag{2}$$

It is easy to prove formula (2): adding each inequality in formula (1), and we can get formula (2) according to $\sum_{i=1}^{n} \lambda_i = 1$. The formula (2) has obvious economic implications. On the whole, only when the sum of the whole net benefit in R&D network are higher than the sum of all enterprises separately do R&D activities, the R&D network will forms. We call the inequalities condition (2) "macro conditions", because it is the total decision-making basis on forming R&D network.

Further more, under simple benefit distribution mode, the "micro condition" (1) is stronger than the "macro condition" (2) of the Nash equilibrium of n enterprises' cooperation. That is, when the "micro condition" is established, the "macro condition" must be established. But when the "macro condition" is established, the "micro condition" may not.

Then we will demonstrate that the condition of the Nash equilibrium of n enterprises' cooperation will be loosened to inequalities condition (2) when we introduce the mechanism of benefit transfer. That means the mechanism of benefit transfer can promote R&D network to attain a Nash equilibrium in wide range condition, so the mechanism benefits the formation of R&D network.

3. R&D network game model while introducing the mechanism of benefit transfer

Under the basic hypothesis of n enterprises, denote a mechanism of benefit transfer using cooperation distribution by $\delta(\delta_1, \delta_2, ..., \delta_n)$, the profit of each enterprise's benefit transfer is $\delta_i R$, and meets $\sum_{i=1}^{n} \delta_i = 0$. So the R&D benefit which is distributed to the ith enterprise in the R&D network is $\lambda_i R + \delta_i R$. $\lambda_i = I_i / I$ means the original distribution scale of benefit, which is equal to input scale, and $\sum_{i=1}^{n} \lambda_i = 1$, $\lambda_i \geq 0$.

Assume net benefit is the only factor enterprise consider during R&D decision. If we expect each enterprise is willing to join the R&D network when there exists mechanism of benefit transfer, the micro condition of n enterprises cooperate is as follows:

$$\lambda_i R + \delta_i R \geq R_i, \ \forall i = 1,2,...,n \tag{3}$$

If inequalities condition (3) are met, each enterprise joining in the R&D network can get more benefit than doing R&D activities separately, so they have no intention to leave the R&D network. That means joining in the R&D network is the Nash equilibrium.

In the following, we consider the relationship between "micro conditions" (3) when existing mechanism of benefit transfer and "macro conditions" (2) of the development of R&D network. In the paper, we raise the following propositions:

Proposition 1(micro conditions $\Rightarrow$ macro conditions):for any mechanism of benefit transfer $\delta(\delta_1, \delta_2, ..., \delta_n)$, if $\lambda_i R + \delta_i R \geq R_i, \forall i = 1,2,...,n$ are established, we can get the result $R \geq \sum_{i=1}^{n} R_i$. In the formula, $\sum_{i=1}^{n} \lambda_i = 1$, $\lambda_i \geq 0, \sum_{i=1}^{n} \delta_i = 0$.

Proof:
Since $\lambda_i R + \delta_i R \geq R_i$, $\forall i = 1,2,...,n$, add the inequalities above, we can get the following inequalities:

$$(\sum_{i=1}^{n} \lambda_i + \sum_{i=1}^{n} \delta_i) R \geq \sum_{i=1}^{n} R_i$$

Because of the conditions $\sum_{i=1}^{n} \lambda_i = 1$ and $\sum_{i=1}^{n} \delta_i = 0$, we obtain:

$$R \geq \sum_{i=1}^{n} R_i$$

Prove up.
Proposition 1 explains that "macro conditions" (2) is the necessary condition of "micro conditions" (3). It means that the R&D network can form only when the whole net benefit of the R&D network are larger than the sum of all the benefit of n enterprises' doing R&D activities alone. As the Proposition 1 is proved, its contrapositive proposition is also true. That is when the "macro conditions" (2) isn't met, the "micro conditions" (3) isn't met neither. Or we can say that when the "macro conditions" (2) is not established, there will be no mechanism of benefit transfer $\delta(\delta_1, \delta_2, ..., \delta_n)$ which make joining in R&D network become game's Nash equilibrium.

The following Proposition 2 shows the "macro conditions" (2) is also the necessary condition of "micro conditions" (3), which means if the whole net benefit is higher than the sum of all enterprises separately do R&D activities, there exists a mechanism of benefit transfer $\delta(\delta_1, \delta_2, ..., \delta_n)$ to establish the inequalities required by the "micro conditions" (3) .

Proposition 2(macro conditions $\Rightarrow$ micro condition): if $R \geq \sum_{i=1}^{n} R_i$ is established, there exists at least one mechanism of benefit transfer $\delta(\delta_1, \delta_2, ..., \delta_n)$, meet $\lambda_i R + \delta_i R \geq R_i$, $\forall i = 1,2,...,n$ .In the formula, $\sum_{i=1}^{n} \lambda_i = 1, \lambda_i \geq 0$, $\sum_{i=1}^{n} \delta_i = 0$.

Proof:
For inequalities:

$$\lambda_i R + \delta_i R \geq R_i, i = 1,2,...,n \tag{4}$$

$$\text{s.t.} \sum_{i=1}^{n} \lambda_i = 1,\ \lambda_i \geq 0 : \sum_{i=1}^{n} \delta_i = 0$$

When $R \geq \sum_{i=1}^{n} R_i$, there always exists a solution vector $\delta^*(\delta_1, \delta_2, ..., \delta_n)$:

$$\delta^*{}_i = \frac{R_i}{R} - \lambda_i + \omega_i (1 - \frac{\sum_{i=1}^{n} R_i}{R}),\ i = 1,2,...,n \tag{5}$$

This is the solution of inequalities(4). In the formula ω_i is weight index, meet $\sum_{i=1}^{n} \omega_i = 1$.

Substitute the formula (5) into formula (4), it is easy to prove that both the inequalities and constraint conditions are established.

Therefore, there exists at least one mechanism of benefit transfer $\delta(\delta_1, \delta_2, ..., \delta_n)$ meeting $\lambda_i R + \delta_i R \geq R_i$, $\forall i = 1,2,...,n$.

Prove up.

Proposition 1 and Proposition 2 mean that , macro conditions $R \geq \sum_{i=1}^{n} R_i$ is the necessary and sufficient condition of micro conditions $\lambda_i R + \delta_i R \geq R_i$ when introducing mechanism of benefit transfer, which is also the necessary and sufficient condition of R&D cooperation's Nash equilibrium.

Eigenvalue method is used to prove proposition 2. There exits a special solution:

$$\delta^*{}_i = \frac{R_i}{R} - \lambda_i + \omega_i (1 - \frac{\sum_{i=1}^{n} R_i}{R}),\ i = 1,2,...,n,\ \sum_{i=1}^{n} \omega_i = 1$$

When $R \geq \sum_{i=1}^{n} R_i$, the solution always meets the inequalities which is required by the micro conditions of the form of R&D network. The solution isn't chosen arbitrarily. When $R \geq \sum_{i=1}^{n} R_i$, the special solution is the gravity center of solutions (the weight mean of each corner solution). It is the game's equilibrium solution.

4. Discussion of R&D network cooperation equilibrium

To discuss the stability of R&D network cooperation, we analyse the micro conditions of cooperation.

$$\lambda_i R + \delta_i R \geq R_i,\ \forall i = 1,2,...,n \tag{6}$$

$$\text{s.t. } \sum_{i=1}^{n} \lambda_i = 1,\ \lambda_i \geq 0 : \sum_{i=1}^{n} \delta_i = 0$$

The solutions of inequalities (6) form a feasible region, and all the solutions in the feasible region can meet the requirement of the form of R&D network. We propose the following proposition about the feasible region:

Proposition 3 (feasible region is convex set): suppose δ^1 and δ^2 are any two mechanisms of benefit transfer meeting (6), and the linear combination $\delta^* = \alpha\delta^1 + \beta\delta^2$ is also a mechanism of benefit transfer meeting (6). In the formula $\alpha \geq 0$, $\beta \geq 0$, $\alpha + \beta = 1$.

Proof: Assume that δ^1 and δ^2 are any two mechanisms of benefit transfer meeting(6). δ_i^1 and δ_i^2 are the ith component, so the linear combination's ith component $\delta_i^* = \alpha\delta_i^1 + \beta\delta_i^2$. Because δ^1 and δ^2 are mechanisms of benefit transfer meeting (6), so we obtain:

$$\lambda_i R + \delta_i^1 R \geq R_i \tag{7}$$

$$\lambda_i R + \delta_i^2 R \geq R_i \tag{8}$$

(7)× α +(8)× β, as $\alpha + \beta = 1$, Get

$$\lambda_i R + \delta_i^* R \geq R_i$$

Besides, as $\sum_{i=1}^{n}\delta_i^1 = 0$, $\sum_{i=1}^{n}\delta_i^2 = 0$, so $\delta_i^* = \alpha\delta_i^1 + \beta\delta_i^2$, $\forall i = 1,2,...,n$. Add these n equations together and we can get $\sum_{i=1}^{n}\delta_i^* = 0$.

Proof up.
Any participant j will maximize his excess benefit in the R&D network

$$\max : \lambda_j R + \delta_j R - R_j,\ j \in \{i | i = 1,2,...,n\}$$

To solve the optimization problem, we can think about it's dual problem, which is all the other participants will get the minimum excess benefit:

$$\min : \lambda_s R + \delta_s R - R_s,\ \forall s \in \{i | i = 1,2,...,n\} \text{ and } s \neq j$$

Because $\lambda_s R + \delta_s R \geq R_s$, so $\lambda_s R + \delta_s R - R_s \geq 0$, that is $\min(\lambda_s R + \delta_s R - R_s) = 0$. When get the min value, $\delta_s = \frac{R_s}{R} - \lambda_s$ $\forall s \in \{i | i = 1,2,...,n\}$ and $s \neq j$.

For participant j, because of the constraint conditions $\sum_{i=1}^{n}\delta_i = 0$, we obtain: $\delta_j = 1 - \frac{\sum_{i=1}^{n} R_i}{R} + \frac{R_j}{R} - \lambda_j$. So we can get the whole excess benefit of the R&D network. And we have the following optimal distribution plan:

Theorem 1 (individual's optimal distribution plan): For participant j, to maximize his excess benefit in the R&D network, the optimal distribution plan:

$$\delta_j = 1 - \frac{\sum_{i=1}^{n} R_i}{R} + \frac{R_j}{R} - \lambda_j,\ \delta_s = \frac{R_s}{R} - \lambda_s,\ \forall s \in \{i | i = 1,2,...,n\} \text{ and } s \neq j \quad (9)$$

Obviously, this is a vertex of the solutions (6). Deduced by analogy, all the individual's optimal distribution plans are get in the vertex of the feasible region.

It is expected that if participant j has enough power, which can impact the benefit distribution of R&D network, the participant j is able to force the R&D network to totally implement his optimal distribution plan. Then the optimal problem of the whole R&D network is the one of participant j. If the benefit distribution plan is deferent from the optimal plan, the participant j will insure the benefit distribution according to (9) through negotiate or other means. In other words, cooperation of other benefit cooperation under this condition is unstable. In the game of R&D network cooperation, the final distribution plan will tend to the optimal distribution plan determined by (9).

Of course, this is an extreme case. Normally, every participant has his own power, so the optimal problem of the whole R&D network is a multi objective programming problem which has n participants:

$$\max : \lambda_j R + \delta_j R - R_j,\ \forall j \in \{i | i = 1,2,...,n\}$$

During the cooperation of R&D network, each participant can realize his own expected optimal distribution plan to certain extent. Because the n participants are unsymmetrical, we define a power factor ω_i of R&D network. Namely, the weight of the optimal distribution plan which each participant expects is ω_i, which meets $\sum_{i=1}^{n}\omega_i = 1$.

By using method of weighting to solve multi objective programming problems, we know the final stable distribution plan is the linear combination of each vertex. The combination coefficient is vector of weighting $\omega(\omega_1, \omega_2, ..., \omega_n)$, and the solution which feasible region is convex set got from proposition 3 ensures that the linear combination must meet the condition (6). So we have the following proposition:

Proposition 2 (the whole optimal distribution plan): Considering the need of all participants in R&D network, each participant will maximize their own excess benefit in the R&D network. So the optimal distribution plan of multi objective programming problem of R&D network:

$$\delta^*_i = \frac{R_i}{R} - \lambda_i + \omega_i (1 - \frac{\sum_{i=1}^{n} R_i}{R}),\ i = 1,2,...,n \tag{10}$$

If the benefit distribution plan is different from the optimal plan above, each participant will insure the benefit distribution according to (10) through negotiate or other means. In other words, cooperation of other benefit cooperation under this condition is unstable. In the game of R&D network cooperation, the final distribution plan will tend to the optimal distribution plan determined by (10).

Given some special value of weighting vectors, we can easily get some special conditions of (10):

When $\omega_j = 1, \omega_s = 0$ ($\forall s \neq j$), the solution degenerate condition(9).

When $\omega_j = 1/n$ ($\forall j = 1,2,...,n$), the negotiation abilities of every participant are symmetrical, the symmetrical game cooperation equilibrium is got in the geometry center of solutions:

$$\delta^*_j = \frac{R_j}{R} - \lambda_j + \frac{1}{n}(1 - \frac{\sum_{j=1}^{n} R_j}{R}),\ j = 1,2,...,n$$

A relatively reasonable distribution of negotiation ability is that the participant's input of R&D is corresponding to its weight of power. That is $\omega_j = \lambda_j$, the cooperation equilibrium of game is:

$$\delta^*_j = \frac{R_j}{R} - \lambda_j \frac{\sum_{j=1}^{n} R_j}{R},\ j = 1,2,...,n$$

DISCUSSION AND CONCLUSION

The paper discusses n enterprises' R&D network unsymmetry game model. Through mechanisms of benefit transfer, the R&D network can have Nash equilibrium in broader conditions. So the mechanism is favour of the form of R&D network. During the R&D network cooperation, we can get the following conclusions:

The R&D network cooperation can realize only when the R&D network can increase the whole benefit.

If an enterprise has great R&D power alone, then the R&D network must compensate for it through mechanisms of benefit transfer in order to attain the cooperation equilibrium of R&D network better.

The compensation of R&D network is also influenced by each participant's negotiation ability. If participants have some resource or power, they will have the compensation from the mechanisms of benefit transfer.

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