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Analysis of Profit Allocation in Technology Innovation Alliance Game Model of Industrial Chain

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Abstract

Due to the features (multi-agent、cross-region、multi-module) of Technology Innovation Alliance, the management problem related to profit allocation is emerging. According to the situation technology innovation influences the marginal revenue and the market demand of products, this paper establishes the game model of the Technology Innovation Alliance consisting of an upstream enterprise and a downstream enterprise in industrial chain. Based on the three league mode(no-league、half-league、all-league), we study the profit distribution range of the upstream and downstream enterprises in industrial chain.

Key words: Technology Innovation Alliance; Industrial chain; Profit allocation; Game theory

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INTRODUCTION

In many industrial chains, with economic globalization and alliance of technology innovations, a single enterprise is facing increasing competitive pressure, the difficulty and investment of technology innovation is growing, the risk is getting higher and higher. The environment has forced companies to seek external opportunities for cooperation, in order to increase competitiveness. Thus, Technology innovation alliance becomes an important means of getting R&D resources and maintaining the competitive advantage for corporate. At the same time, with the improvement of the level of consumer income, the technological content of products has become an important factor that influences customer buying behavior. Therefore, the market demand of many products (such as mobile phones, laptops, instant messaging software, etc.) has a high sensitivity to technological innovation. The sensitivity of the market demand for technology innovation will have a significant impact on the alliance interest of the industry chain upstream and downstream enterprises.

The problem of alliance has done a lot of research at home and abroad. David (1997) described the profit sharing mechanism of collaborative R&D and virtual research from the perspective of knowledge sharing. Banerjee and Lin (2001) established the model of longitudinal R&D cooperation, and discussed the influence of the different cooperation R&D strategy to innovation activities of the upstream and downstream enterprises. Karl (2002) analyzed the distribution of profits between the upstream and downstream enterprises by Principal-agent model. Cachon and Larivere (2005) proposed the general framework of revenue sharing contract, and proved revenue sharing contract mechanism can achieve better results compared to traditional coordinated program. Jaber and Goyal (2008) explored the profit distribution of the three supply chain. PAN Hui-ping and CHENG Rong-qiu (2005) discussed profit allocation between manufacturers and distributors. From the perspective of industry chain, LIU Zhiying (2010 & 2012) constructed the innovative profit model of cooperative innovation of industry chain consisting of the supplier and the manufacturer. ZhangSheng Jiang (2011) established Master-slave Game Model of Technology innovation alliance from the perspective of knowledge transfer. However, these studies did not consider that the technology innovation has affected the marginal benefits of enterprise products and the market demand. In this

case, how to carry out the investment in technology innovation, alliance formation and distribution of profits for the upstream and downstream enterprises of Industrial chain. In view of this, according to the situation that technology innovation influences the marginal revenue and the market demand of products, this paper establishes the game model of the Technology Innovation Alliance. Based on the three league mode(no-league、half-league、all-league), we study the profit distribution mechanism of the upstream and downstream enterprises in industrial chain.

1. DESCRIPTION OF THE PROBLEM

Considering the Technology Innovation Alliance consisting of an upstream enterprise and a downstream enterprise in industrial chain, upstream firm provides an intermediate product to downstream firm, downstream firm assembles a unit of final product by using a unit of the intermediate product. The upstream and downstream enterprises in industrial chain decide to carry out technological innovation activities. The activities not only increase the marginal revenue of the product, but also make the market demand function move to the right.

The game process on the production, pricing, technological innovation, and the distribution of profits between upstream and downstream enterprises in industrial chain are divided into: Phase 0, the alliance decides profit distribution mechanism; Phase1, the upstream and downstream enterprises in industrial chain make decision of technology innovation investment; Phase2, the upstream and downstream enterprises in industrial chain carry out Stackelberg Berg game on the yield of the final product and intermediate goods prices. Whether there is cooperation based on the latter two phases, the game can be divided into three forms, the first is no-league (subscript 1 indicates).This is not to cooperate on the production and technology innovation investment, each determines technology innovation investment, intermediate goods prices and production to their own profit maximization as the goal. The second is half-league(subscript 2 indicates) .This is not to cooperate on the production but to cooperate on technology innovation investment, each determines intermediate goods prices and production to their own profit maximization as the goal ,but they determine technology innovation investment to maximize the overall profit as the goal. The third isall-league(subscript 3 indicates). This is to cooperate on the production and technology innovation investment, they determine production and technology innovation investment to maximize the overall profit as the goal.

2. MODELING AND SOLVING

2.1 Modeling

In technology innovation alliance, let w is the intermediate goods prices that the upstream enterprise (expressed in s) sold to the downstream enterprise (expressed in m);P is the final product prices that the downstream enterprise sold to customers;C_s, C_m(before technology innovation)are unit production cost of the upstream and downstream enterprises; x_s is the technology innovations of upstream enterprise; x_m is the technology innovations of downstream enterprise; C(x_i)(i=s,m)is the technology innovation cost of the upstream and downstream enterprises, $C(x_i)=\frac{\gamma}{2}x_i^2\ (\gamma>0)$ is quadratic function of xi.The inverse demand function of products is related to production and technology innovation of upstream and downstream enterprises, then $P=a+\beta_s x_s+\beta_m x_m-bQ.\beta_s$, β_m, b are sensitive coefficients between market demand and technology innovation of upstream and downstream enterprises, production. Meanwhile, members of technology innovation alliance are rational economic man, the alliance is no technology spillover and risk-neutral. They are fully sharing information with each other, and the goal is to maximize profits.

There are profit functions of upstream, downstream and the whole industry chain:

$$\prod_{\mathrm{s}}=(w-C_s+x_s)Q-\frac{\gamma}{2}x_s^2 \tag{1}$$

$$\prod_{\mathrm{m}}=(P-w-C_m+x_m)Q-\frac{\gamma}{2}x_m^2 \tag{2}$$

$$\prod=\prod_{\mathrm{s}}+\prod_{\mathrm{m}}=(P-C_s-C_m+x_s+x_m)Q-\frac{\gamma}{2}(x_s^2+x_m^2) \tag{3}$$

2.2 Solving

We use backward induction to solve the game.

2.2.1 No-league

In the no-league, it is not to cooperate on the production and technology innovation investment of the upstream and downstream enterprises. First, downstream enterprise selects production Q to its own profit maximization. Solving $\frac{\partial\prod_{\mathrm{m1}}}{\partial Q_1}=0$ to obtain:

$$Q_1=\frac{a-C_m+\beta_s x_s+\beta_m x_m+x_m-w_1}{2b} \tag{4}$$

Then, the upstream enterprise determines the transfer prices of intermediate goods w. Solving $\frac{\partial\prod_{\mathrm{s1}}}{\partial w_1}=0$ to obtain:

$$w_1=\frac{a-C_m+C_s+\beta_s x_s+\beta_m x_m+x_m-x_s}{2} \tag{5}$$

We put formula (4), (5) into the profit function of the upstream and downstream enterprises. Solving $\frac{\partial \prod_{s1}}{\partial x_{s1}} = 0$, $\frac{\partial \prod_{m1}}{\partial x_{m1}} = 0$ to obtain:

$$x_{s1}^{*} = \frac{2(\beta_s + 1)A}{H_1} \tag{6}$$

$$x_{m1}^{*} = \frac{(\beta_m + 1)A}{H_1} \tag{7}$$

And, $A = a - C_s - C_m$

$$H_1 = 8b\gamma - 2(\beta_s + 1)^2 - (\beta_m + 1)^2$$

We put formula (6), (7) into formula (1), (2), (3), (4), (5) to obtain:

$$Q_1^{*} = \frac{2\gamma A}{H_1} \tag{8}$$

$$w_1^{*} = \frac{1}{2}\left[a - C_m + C_s + \frac{2(\beta_s - 1)(\beta_s + 1)A}{H_1} + \frac{(\beta_m + 1)^2 A}{H_1}\right] \tag{9}$$

$$\prod_{s1}^{*} = \frac{2\gamma A^2}{H_1^2}\left[4b\gamma - (\beta_s + 1)^2\right] \tag{10}$$

$$\prod_{m1}^{*} = \frac{\gamma A^2}{2H_1^2}\left[8b\gamma - (\beta_m + 1)^2\right] \tag{11}$$

$$\prod_{1}^{*} = \frac{\gamma A^2}{2H_1^2}\left[24b\gamma - 4(\beta_s + 1)^2 - (\beta_m + 1)^2\right] \tag{12}$$

2.2.2 Half-league

In the half-league, it is not to cooperate on the production but to cooperate on technology innovation investment of the upstream and downstream enterprises. The decision-making in the production and intermediate goods prices in this stage of the game is the same with the no-league:

$$Q_2 = Q_1 = \frac{a - C_m + \beta_s x_s + \beta_m x_m + x_m - w_1}{2b} \tag{13}$$

$$w_2 = w_1 = \frac{a - C_m + C_s + \beta_s x_s + \beta_m x_m + x_m - x_s}{2} \tag{14}$$

The upstream and downstream enterprises jointly decide the innovations. Solving $\frac{\partial \sum \prod_{i2}}{\partial x_{i2}} = 0$ to obtain:

$$x_{s2}^{*} = \frac{3(\beta_s + 1)A}{H_2} \tag{15}$$

$$x_{m2}^{*} = \frac{3(\beta_m + 1)A}{H_2} \tag{16}$$

And, $H_2 = 8b\gamma - 3(\beta_s + 1)^2 - 3(\beta_m + 1)^2$.

We put formula (15), (16) into formula (1), (2), (3), (13), (14) to obtain:

$$Q_2^{*} = \frac{2\gamma A}{H_2} \tag{17}$$

$$w_2^{*} = \frac{1}{2}\left[a - C_m + C_s + \frac{3(\beta_s - 1)(\beta_s + 1)A}{H_2} + \frac{3(\beta_m + 1)^2 A}{H_2}\right] \tag{18}$$

$$\prod_{s2}^{*} = \frac{\gamma A^2}{2H_2^2}\left[16b\gamma - 9(\beta_s + 1)^2\right] \tag{19}$$

$$\prod_{m2}^{*} = \frac{\gamma A^2}{2H_2^2}\left[8b\gamma - 9(\beta_m + 1)^2\right] \tag{20}$$

$$\prod_{2}^{*} = \frac{3\gamma A^2}{2H_2} \tag{21}$$

2.2.3 All-league

In the all-league, it is not to cooperate on the production and technology innovation investment of the upstream and downstream enterprises. First, The upstream and downstream enterprises jointly decide production Q to their own profit maximization. Solving $\frac{\partial \sum \prod_{i2}}{\partial Q_3} = 0$ to obtain:

$$Q_3 = \frac{A + \beta_s x_s + \beta_m x_m + x_s + x_m}{2b} \tag{22}$$

The upstream and downstream enterprises jointly decide the innovations. Solving $\frac{\partial \sum \prod_{i3}}{\partial x_{i3}} = 0$ to obtain:

$$x_{s3}^{*} = \frac{(\beta_s + 1)A}{H_3} \tag{23}$$

$$x_{m3}^{*} = \frac{(\beta_m + 1)A}{H_3} \tag{24}$$

And, $H_3 = 2b\gamma - (\beta_s + 1)^2 - (\beta_m + 1)^2$.

We put formula (23), (24) into formula (3), (22) to obtain:

$$Q_3^{*} = \frac{\gamma A}{H_3} \tag{25}$$

$$\prod_{3}^{*} = \frac{\gamma A^2}{2H_3} \tag{26}$$

3. PROFIT ALLOCATION

3.1 All-league

In the all-league, the upstream and downstream enterprises are to cooperate on the production and technology innovation investment to increase the overall profit of the industry chain. From the equilibrium solution of the all-league, we know the profits of the upstream and downstream enterprises are vague, their profits should be distributed. The following is to discuss the distribution of

profits of the all-league, according to the three situations of upstream dominance, downstream dominance and the dominance of the upstream and downstream enterprises distinguishing obvious.

3.1.1 Upstream Dominance

When the upstream enterprise is in a dominant position in the alliance, the upstream enterprise has a strong bargaining power. As a "perfectly rational people", the upstream enterprise must set the intermediate goods prices w according to the following criteria: the profit of the downstream enterprise in the all-league Π_{m3}^{*} is exactly equal to its retained profits Π_{m2}^{*}(the profit in the half-league). In this way, the downstream enterprise is willing to participate in the all-league, and the upstream enterprise is also to obtain all profits increased in the all-league.

Solving $\Pi_{m3}^{*}=\Pi_{m2}^{*}$to obtain the intermediate goods prices

$$w_3^{*} = a - C_m + \frac{A\mathrm{X}}{2H_3} - \frac{H_3 A\mathrm{Y}}{2H_2^{\,2}}$$

($\mathrm{X}=2\beta_s(\beta_s+1)+(\beta_m+1)^2-2b\gamma$, $\mathrm{Y}=8b\gamma-9(\beta_m+1)^2$).

The profit of upstream enterprise is

$$\Pi_{s3}^{*} = \frac{\gamma A^2}{2H_2^{\,2}H_3}\left\{\left[16b\gamma-9(\beta_s+1)^2\right]H_3+2b\gamma H_2\right\},$$ the profit of downstream enterprise is

$$\Pi_{m3}^{*} = \frac{\gamma A^2}{2H_2^{\,2}}\left[8b\gamma-9(\beta_m+1)^2\right].$$

3.1.2 Downstream Dominance

When the downstream enterprise is in a dominant position in the alliance, the downstream enterprise has a strong bargaining power. As a "perfectly rational people", the downstream enterprise must set the intermediate goods prices *w* according to the following criteria: the profit of the upstream enterprise in the all-league Π_{s3}^{*} is exactly equal to its retained profits Π_{s2}^{*}(the profit in the half-league). In this way, the upstream enterprise is willing to participate in the all-league, and the downstream enterprise is also to obtain all profits increased in the all-league.

Solving $\Pi_{s2}^{*}=\Pi_{s3}^{*}$to obtain the intermediate goods prices

$$w_3^{*} = C_s + \frac{A}{2H_3}(\beta_s-1)(\beta_s+1) + \frac{H_3 A\mathrm{Z}}{2H_2^{\,2}}$$

($\mathrm{Z}=16b\gamma-9(\beta_s+1)^2$). The profit of upstream enterprise is $\Pi_{s3}^{*} = \frac{\gamma A^2\mathrm{Z}}{2H_2^{\,2}}$, the profit of downstream enterprise is

$$\Pi_{m3}^{*} = \frac{\gamma A^2}{2H_2^{\,2}H_3}\left\{\left[8b\gamma-9(\beta_m+1)^2\right]H_3+2b\gamma H_2\right\}.$$

Conclusion 1: When the status of the upstream and downstream enterprises is different, the intermediate goods prices *w* and the profits of upstream and downstream enterprise are also different. When the upstream enterprise is in a dominant position in the alliance and has a strong bargaining power, the upstream enterprise will set the intermediate goods prices w to obtain all profits increased in the cooperation. On the contrary, when the downstream enterprise is in a dominant position in the alliance and has a strong bargaining power, the downstream enterprise will set the intermediate goods prices w to obtain all profits increased in the cooperation. But in reality, this allocation mechanism is likely to lead to dissatisfaction of a party in follower status in the all-league .When they cooperate with each other, a party in follower status can take opportunistic behavior, to affect the stable operation of the all-league.

3.1.3 The Dominance of the Upstream and Downstream Enterprises is Distinguished Obvious

When the dominance of the upstream and downstream enterprises is distinguished obvious, we can use the proportional distribution method of technology innovations to distribute the profit increased in the all-league. The technology innovations of upstream and downstream enterprises are $x_{s3}^{*} = \frac{(\beta_s+1)A}{H_3}$, $x_{m3}^{*} = \frac{(\beta_m+1)A}{H_3}$. The distribution proportion of the profit increased in the all-league are $\delta_s = \frac{\beta_s+1}{\beta_s+\beta_m+2}$, $\delta_m = \frac{\beta_m+1}{\beta_s+\beta_m+2}$. According to equation formula (21), (26), the profit increased in the all-league is $\Delta\Pi_{23} = \Pi_3^{*} - \Pi_2^{*} = \frac{b\gamma^2A^2}{H_2H_3}$.

Solving

$\Pi_{s3}^{*} = \Pi_{s2}^{*} + \frac{\beta_s+1}{\beta_s+\beta_m+2}\Delta_{23}$ to obtain the intermediate goods prices

$$w_3^{*} = C_s + \frac{A(\beta_s-1)(\beta_s+1)}{2H_3} + \frac{H_3 AZ}{2H_2^{\,2}} + \frac{b\gamma(\beta_s+1)A}{(\beta_s+\beta_m+2)H_2}.$$

The profit of upstream enterprise is

$$\Pi_{s3}^{*} = \frac{\mathrm{Z}(\beta_s+\beta_m+2)H_3+2b\gamma(\beta_s+1)H_2}{2H_2^{\,2}H_3(\beta_s+\beta_m+2)}\gamma A^2,$$ the profit of downstream enterprise is

$$\Pi_{m3}^{*} = \frac{\mathrm{Y}(\beta_s+\beta_m+2)H_3+2b\gamma(\beta_m+1)H_2}{2H_2^{\,2}H_3(\beta_s+\beta_m+2)}\gamma A^2.$$

Conclusion 2: When we use the proportional distribution method of technology innovations, the upstream and downstream enterprises distribute the profit increased in the all-league by their own technology innovations. Thus, they both increase the profit. This is

more conducive to raise enthusiasms of full cooperation in both sides.

3.2 Half-league

In the half-league, the upstream and downstream enterprises are to cooperate on the technology innovation investment to increase the overall profit of the industry chain. In the technological innovation cooperation, when the upstream enterprise has technical advantages, the upstream enterprise is in a dominant position. It guides downstream enterprise to carry out technology innovation. This can promote the technical accordance between the upstream and downstream enterprises to improve technology innovations. On the contrary, when the downstream enterprise has technical advantages, the downstream enterprise is in a dominant position. It guides upstream enterprise to carry out technology innovation. This can promote the technical accordance between the upstream and downstream enterprises to improve technology innovations. Therefore, regardless of upstream enterprise or downstream enterprise is in a dominant position, the dominant enterprise will get a proportion of the profit-sharing from the followers to compensate for its contribution to the alliance.

3.2.1 Upstream Dominance

When the upstream enterprise is in a dominant position in the alliance, as a "perfectly rational people", the upstream enterprise must get the profit-sharing λ from the downstream enterprise. And ensuring the residual profits of the downstream enterprise in the half-league $(1-\lambda)\Pi_{m2}^{*}$ is greater than or equal to its retained profits Π_{m1}^{*} (in the no-league).

Solving $(1-\lambda)\prod_{m2}^{*} \geq \prod_{m1}^{*}$ to obtain

$$0 < \lambda \leq 1 - \frac{H_2^{\,2}\left[8b\gamma - (\beta_m + 1)^2\right]}{H_1^{\,2}\left[8b\gamma - 9(\beta_m + 1)^2\right]}.$$

3.2.2 Downstream Dominance

When the downstream enterprise is in a dominant position in the alliance, as a "perfectly rational people", the downstream enterprise must get the profit-sharing λ from the upstream enterprise. And ensuring the residual profits of the upstream enterprise in the half-league $(1-\lambda)\prod_{s2}^{*}$ is greater than or equal to its retained profits $\prod_{s1}^{*}$ (in the no-league).

Solving $(1-\lambda)\prod_{s2}^{*} \geq \prod_{s1}^{*}$ to obtain

$$0 < \lambda \leq 1 - \frac{H_2^{\,2}\left[16b\gamma - 4(\beta_s + 1)^2\right]}{H_1^{\,2}\left[16b\gamma - 9(\beta_s + 1)^2\right]}.$$

Conclusion 3: In the half-league, regardless of upstream enterprise or downstream enterprise is in a dominant position, the overall profits of the industry chain will be re-allocated by the upstream and downstream enterprises in industry chain. The dominant enterprise will get the profit-sharing from the followers. And ensuring the residual profits of the followers is greater than or equal to its retained profits in the no-league to affect the stable operation of the alliance.

CONCLUSION

In the situation that the market demand is sensitive to technology innovation on the market, the sensitivity of the demand for innovation will change the overall profit of the industry chain. Through research, we reach conclusion that the all-league not only maximizes the benefits of alliance, but also maximizes the benefits of single enterprise. And we dish the profit distribution mechanism in the all-league and half-league by the status of the upstream and downstream enterprises and the proportion of technological innovations. In response to these findings, we believe that there are the following policy implications:(1)The substantive cooperation in technology innovation alliance can maximize the benefits of alliance, and promote the stable operation of the alliance;(2)The different modes of alliance can affect the profit distribution mechanism of alliance;(3)The government should establish the profit distribution mechanism of technology innovation alliance through policy guidance, and promote the substantive cooperation of alliance.

Based on the alliance members are rational people and the alliance which is no technology spillover and risk-neutral, we built the model. We do not consider irrational factors of alliance members and the impact of risk preferences. In the Real life, the alliance members are usually bounded rationality and risk appetite. Therefore, future research can be further considered the profit distribution mechanism of technology innovation alliance in the case of the existence of irrational factors and risk appetite.

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