An Evolutionary Game Analysis of Information Sharing Behavior for Cluster Supply Chain

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Abstract—From the perspective of evolutionary game, this paper demonstrates the internal mechanism and evolution process of information sharing among horizontal enterprises in the cluster supply chain. Our results show that the number of information sharing, the marginal benefit of information sharing, the ability of information absorption, the incentive coefficient and the penalty coefficient for “free-riding behavior” are positively promoted to the information sharing behavior of enterprises in the supply chain. However, the marginal cost and risk coefficient of information sharing have a negative impact. Based on these influencing factors and the problem existing in the information sharing, the paper puts forward some suggestions to strengthen the awareness of enterprise information sharing, improve the information absorption capacity, establish an information sharing mechanism, and promote the coordinated development of enterprises.

Keywords—supply chain; information sharing; evolutionary game

I. INTRODUCTION

Industry cluster, a kind of carrier of regional economic development, provides a new driver force of cooperative innovation for the enterprises in the supply chain [1-3]. As continuously upgrading and transforming, industry cluster accelerates the speed of assembling homogeneous enterprises in the horizontal supply chain, forming relationship between upstream and downstream enterprises, and coupling into the industry cluster supply chain [4, 5]. It would be better to integrate high-quality resources inside and outside the enterprises and boost competitiveness of supply chain, because of synergy effect that caused by information sharing mechanism among horizontal enterprises [6-9]. However, as future development of technology and informatization, slow response and poor level of trust trouble the enterprises in the supply chain. The research on the behavior of information sharing will provide new theoretical basis and new idea for improving the synergy ability of China's industrial cluster supply chain.

II. MODEL

A. Model Variables and Assumptions

The cooperation between supply chain enterprises in industrial clusters is a cooperative game behavior based on the goal of maximizing public interest. Horizontal enterprises in the cluster supply chain can establish a relatively stable synergy relationship with cooperation. In the supply chain network, manufacturers, retailers, and distributors generate complex network structures. To simplify the supply chain network, we assume that there are two parallel supply chains. At the same time, we study the information sharing behavior of horizontal enterprises in the supply chain.

Hypothesis 1: Supply chain companies make bounded rational decisions.

Hypothesis 2: Information sharing in the process of supply chain enterprises is based on the sharing of demand information. There are also production information and inventory information in the supply chain. Therefore, information asymmetry and incomplete information decision still exist.

The variables are set as follows:

B. Model Establishment of Evolutionary Game

When enterprises in the supply chain play a game of information sharing cooperation, both Enterprise 1 and Enterprise 2 can share information or not share. Therefore, we can get four combination strategies. We assume that the probability that enterprise 1 chooses “information sharing” is x, then the probability of selecting “no information sharing” is 1-x; similarly, if enterprise 2 chooses “information sharing” with a probability of y, then the probability of choosing “no information sharing” is 1-y. The supply chain structure is shown as Fig. 1.
If \( x^* = y^* \), then \( F(x^*) = 0 \) is the evolutionary stability strategy of enterprise 1. Therefore, enterprises tend not to share information.

2) Stability analysis of enterprise 2 strategy: Suppose that the expected return of enterprise 2 selecting “information sharing” is \( y^* \), then \( F(y^*) < 0 \) is the evolutionary stability strategy of enterprise 2. When \( y > y^* \), then \( y^* = 1 \). \( F(y^*) < 0 \) is the evolutionary stability strategy of enterprise 2. At this time, enterprise 2 chooses to share information.

2.1) Stability analysis of enterprise 2 strategy: Suppose that the expected return of enterprise 2 selecting “no information sharing” is \( u_{21} \). The average expected return of enterprise 2 selecting “information sharing” and “non-information sharing” is \( u_{22} \).

\[
\begin{align*}
F(y) &= \frac{dy}{dx} = \gamma(u_{12} - u_1) - (1 - \gamma)(u_{11} - u_1)y
\end{align*}
\]

When \( F(y^*) = 0 \), \( y^* \) is the stable point of the replication dynamic equation. Since the stability strategy of evolutionary game is anti-interference, \( y^* \) is the stable strategy of evolutionary game when \( F(y^*) = 0 \) and \( F(y^*) < 0 \).

a) When \( a_1 t_1 + b_1 s_1 m_1 t_2 < n_1 t_1 + c_1 t_2 \), \( y = 0 \), then \( F(y) = 0 \) is the evolutionary stability strategy of enterprise 1. Therefore, enterprises tend not to share information.

b) When \( a_1 t_1 + b_1 s_1 m_1 t_2 > n_1 t_1 + c_1 t_2 \), \( y = 0 \), then \( F(y) = 0 \) is the evolutionary stability strategy of enterprise 2. Therefore, enterprises tend not to share information.

3) Stability analysis of strategies between both parties: The dynamic system of the evolutionary game of information sharing between enterprise 1 and enterprise 2 is formed by the combination of equations (1) and (2).

\[
F(x) = x(1 - x)[(a_1 t_1 + b_1 s_1 m_1 t_2) - (n_1 t_1 + c_1 t_2)]
\]

For the convenience of computing, we set

\[
\Pi_1 = a_1 t_1 + b_1 s_1 m_1 t_2, \quad \Pi_2 = a_2 t_2 + b_2 s_2 m_2 t_2
\]

At this time, the evolutionary game of the horizontal supply chain of the cluster supply chain under information sharing has the following four situations.

a) When \( p_1 > \Pi_1, p_2 > \Pi_2 \): the phase diagram can be simulated by the dynamic equation of the game. It can be seen from Fig. 2 that after repeated game between enterprise 1 and enterprise 2, they choose not to share information, so they
When $p_1 < \Pi_1, p_2 > \Pi_2$: As can be seen from Fig. 3, enterprise 2 is still in the same situation as Case 1 and chooses to use the information sharing strategy. However, the choice of enterprise 1 changes with the evolution stage. In the initial stage, when $y > y^*$, the proportion of information sharing strategies selected by enterprise 2 increases with the evolution of the game; when $y < y^*$, the enterprise 1 finds that the benefit of not sharing information is greater than the benefit of sharing information. Therefore, the strategy gradually converges to $(0, 0)$. The final evolutionary game stabilization strategy still does not share information.

When $p_1 > \Pi_1, p_2 < \Pi_2$: As can be seen from Fig. 4, enterprise 1 is still in the same situation as case 1, and still chooses to use the information sharing strategy. However, the choice of enterprise 2 changes with the evolution stage. In the initial stage, when $x > x^*$, with the evolution of the game, the proportion of enterprises choosing information sharing strategy is increasing; when $x > x^*$, enterprise 2 finds that the benefit of not sharing information is greater than the benefit of sharing information. Therefore, the strategy gradually convergence to $(0, 0)$. The final evolutionary game stabilization strategy still does not share information.

When $p_1 < \Pi_1, p_2 < \Pi_2$: When the strategy converges to C$(0,0)$ and B$(1,1)$, the stability strategy is that both enterprise 1 and 2 choose to share information or not, but the stability strategy is unique. The ultimate stabilization strategy depends on the initial willingness of enterprise 1 and 2 to share information. As shown in Fig. 5, when the initial willingness of enterprise 1 and 2 is in the area BECD in equations 5, the evolutionary game will converge to D$(1,1)$. At this time, the stability strategy of the evolutionary game is that enterprise 1 and 2 choose to share information. When the initial willingness of Enterprise 1 and Enterprise 2 is in the area ACDE, the evolutionary game converges to A$(0,0)$. At this time, the stable strategy of the evolutionary game is that enterprise 1 and 2 choose not to share information.

The impact of various factors on the evolutionary game is as follows.

The amount of information sharing $t_{ij}$. When both enterprise 1 and enterprise 2 choose information sharing, the cluster supply chain formed by the enterprise has the largest revenue. The gain at this time is $s_1m_1t_2 + a_1t_1 - n_1t_3 - c_1t_4 + s_2m_2t_1 + a_2t_2 - n_2t_2 - c_2t_2$. Therefore, when the enterprise expands the information sharing amount, it can promote the overall benefit to the greatest extent and form a chain effect, which improves the enthusiasm of enterprise information sharing in the industrial cluster to a certain extent.

Information sharing marginal cost coefficient $s_i$. The smaller the $s_i$ is, the smaller ESS is. At this time, the larger the area, the more likely the enterprise is to share information. When the cost factor is too high, the initial willingness of the company to share information will be greatly reduced. Therefore, the reduction of the marginal cost coefficient can promote the synergy of enterprises and ensure that information is exchanged among cluster supply chains.

Information sharing risk factor $m_i$. In the process of information sharing, it is inevitable that there will be problems such as leakage of trade secrets and default of enterprises, which brings certain risks to the information sharing behavior among enterprises and increases the uncertainty of the information sharing. Only by improving the information sharing mechanism and minimizing the risk caused by information sharing can the enterprise achieve win-win.
Information absorption coefficient $\eta_l$. Then the position of ESS will move to the lower left of the coordinate axis and the area will increase. Then, the probability that each node enterprise in the supply chain selects the “information sharing” strategy will also increase. The information absorption capacity of each node in the supply chain affects the benefits that enterprises obtain through information sharing. However, the information literacy of each node in the supply chain is mixed, which will affect the company's willingness to choose the “information sharing” strategy. Nowadays, all the nodes in the supply chain are in the market environment of information explosion. Faced with such information pressure, if each node enterprise can't keep pace with the times and enhance its information literacy, then each node enterprise will eventually be eliminated by the market. This requires each node enterprise in the supply chain to strengthen the reform of information technology and enhance the information literacy of employees, so as to enhance the information absorption capacity of enterprises.

Incentive coefficient $\alpha_l$ and penalty factor $b_l$. In the process of forming the information sharing mechanism, when $\alpha_l$ becomes larger and $b_l$ becomes smaller, the area becomes larger. Therefore, the initial willingness of enterprises to share information increases. On the one hand, the introduction of incentives by enterprises can drive the enthusiasm among enterprises. On the other hand, the punishment of “free-riding” can let enterprises understand the serious consequences of speculation and participate in sharing behavior more actively.

III. NUMERICAL EXAMPLE AND COOPERATION STRATEGY

Verify the correctness of the model analysis by assigning values to variables. The assignment result is as follows:

| Notation | Enterprise1 | Enterprise2 |
|----------|-------------|-------------|
| $t_l$    | 6           | 4           |
| $s_l$    | 0.5         | 0.4         |
| $c_l$    | 0.1         | 0.2         |
| $m_l$    | 0.8         | 0.7         |
| $n_l$    | 0.1         | 0.2         |
| $a_l$    | 0.5         | 0.6         |
| $b_l$    | 1.5         | 1.2         |
| $\lambda(y)$ | 0.5 | 0.6 |

As shown in Fig. 6, $F(x,y) = (0.5,0.6) > F(x^*,y^*) = (0.2625,0.2222)$. Although companies 1 and 2 are not willing to share information at first, with the repeated game between enterprises, enterprises 1 and 2 choose to share information through trial and error adjustment strategy.

IV. CONCLUSION

Based on the asymmetric evolutionary game theory, this paper mainly explores the horizontal information sharing behavior, evolutionary path of information sharing in four situations, and the mechanism of some enterprises' characteristics on the information sharing behavior of enterprises. The initial state of enterprises’ willingness to share determine the stable information sharing strategy among enterprises, including both sharing or both non-sharing. The characteristics of enterprises (cost coefficient of information sharing, marginal benefit coefficient of information contribution, risk coefficient of information sharing, information absorption coefficient, incentive coefficient of information sharing, punishment coefficient and information sharing) determine the ESS, which would affect the ultimate stability strategy of the game. Therefore, we could know that it would be necessary to increase synergy ability and reduce risk of information sharing in order to promote development of information sharing strategy. On the one hand, the amount of information sharing depends on the enterprise comprehensive strength. On the other hand, introducing incentive and punishment mechanism of the government could help enterprises in the cluster industry form a more stable synergy relationship.

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