Evolutionary Game Analysis of Knowledge Sharing in Asymmetric Upstream and Downstream Enterprises of Supply Chain

Hengshan Zong, Guozhu Jia, Feng Jin, and Jili Kong
School of Economics and Management, Beihang University, Beijing, China

Abstract—As the core of the production means of enterprises, knowledge has become the strategic resource of the supply chain. Through the knowledge sharing among the enterprises in the supply chain, the efficiency of knowledge innovation and application can be improved. In this paper, based on the state-of-the-art literature, the evolutionary game model of asymmetric upstream and downstream enterprises in the supply chain is built; the dynamic evolutionary process and the influencing factors of the selection of knowledge sharing strategies are analyzed. Based on those analyses, the results show that selecting knowledge sharing strategy in the upstream and downstream enterprises are affected by the factors: the cost coefficient of knowledge sharing, the risk coefficient of knowledge sharing, the gap between the amount of knowledge sharing of enterprises, which have negative correlation to selecting knowledge sharing strategy in the upstream and downstream enterprises; the coefficient of gains in social relationships, the synergistic effect coefficient of knowledge sharing, the incentive and punishment factor of knowledge sharing, which have positive correlation to selecting knowledge sharing strategy. On the basis of these factors, the concrete measures to promote knowledge sharing are put forward. This research has a positive significance for remodeling and strengthening the supply chain core advantages in the era of knowledge economy.

Index Terms—Evolutionary Game; Knowledge Sharing; Replicator Dynamics; The Supply Chain

I. INTRODUCTION

Since knowledge sharing between the supply chain members can save the supply chain resources, reduce risks, avoid duplication of development knowledge, and enhance their overall competitiveness [1], it has become a primary strategic resource with the accelerated process of global integration. The existing research related to the supply chain knowledge sharing mainly focuses on the factors influencing that, mechanisms and knowledge sharing models. Among that research, Weng Li carried out the comparison among different decision-making behaviors of knowledge sharing under three situations in order to analyze the effective impacts of the factors of the supply chain knowledge sharing [2]. Besides, Mee-Sheu Cheung and Matthew B.Myers studied the the advantage effect of knowledge sharing in the competition among different companies in the supply chain, and the importance of building sustainable knowledge sharing networks [3] which would guarantee the development of international supply chains. And Wadwa and Saxena proposed a flexible knowledge sharing model of supply chain which considering the cost as a indicator of performance measurement [4]. Zhu Qing constructed four levels of the supply chain knowledge sharing process model, describing the process of knowledge sharing and its mechanisms [5]. Tiezhu Zhang believed that there is dynamic game between the upstream and downstream enterprises in the supply chain and by analyzing the characteristics of Stackelberg model and using the coordination theory of supply chain, the coordination mechanism of the supply chain which has game features of Stackelberg model is proposed [6]. Zhen Li constructed the repeated game model through analyzing the logistics cooperation relations of the inter-enterprises in supply chain, and got the the benefit equilibrium condition of logistics cooperation between enterprises. According to the conditions, the corresponding counter measure are put forwarded [7]. Zhang Yulin analyzed the information demand of a single supplier and a single retailer in supply chain, established the game model of incomplete information in supply chain enterprises, and discussed the condition of the process of sharing information between the supplier and the retailer. It provides a theoretical basis for enterprises practice [8]. Juhong Chen analyzed the knowledge value changes before and after the knowledge sharing process in virtual enterprise, and constructed a game model between the virtual enterprise employees. The relationship factors of knowledge value, cooperation value and alliance effect in game theory model are analyzed, and pointed out the problems which need to be considered in the future research [9]. Lei Ping constructed the three party game model through studying on the two enterprises game condition in the supply chain, and puts forward to some measures for promoting the partnership of cooperative partners [10]. In general, most current studies are qualitative and are not systematic and quantitative. When looking at the present evolution of inter-organizational knowledge sharing for game analysis, the studies are mainly done in the context of industrial clusters [11], dynamic alliance [12], and virtual organizations [13]. And the game analysis of research of the supply chain focuses on inter-firm cooperation and competition [14]. However, the existing game model is too simple and the

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conclusion is too broad and lacks of the effective guidance on practical issues. Plus, the existing study analyses knowledge sharing game theory by using a single factor [15-16]. Actually, there is currently no evolutionary game analysis of knowledge sharing problems among upstream and downstream enterprises in the supply chain. Based on the previous academic studies, in this paper, the supply chain’s evolutionary game model of asymmetric upstream and downstream enterprises is built. Assuming they meet the assumptions, this paper analyses the evolution of a stable trend in different situations between them, including strategic combinations and gains, and summarize the game behavior of each member in different parameters. By analyzing the various factors, the effective regulatory mechanisms between the supply chain members are established, and better enhance the efficiency and effectiveness of the knowledge sharing of the supply chain between the upstream and downstream enterprises.

II. KNOWLEDGE SHARING FEATURES

A. Knowledge Sharing Features in the Upstream and Downstream Enterprises of the Supply Chain

The knowledge sharing of the supply chain enterprises may happen in the same layer, such as between suppliers, manufacturers, distributors, etc. It can also occur in the superior and subordinate enterprises. For instance, between the supplier and manufacturer, the manufacturer and distributor and so on. As you can see from Figure 1, the knowledge sharing activities in the supply chain network are not only located in the in the same layer, but also located in the upstream and downstream enterprises.

![Figure 1. Knowledge share between enterprises in supply chain network](image)

Knowledge sharing mode of enterprises in supply chain network is shown in Figure 3. In a certain political, economic, cultural background, through formal and informal means, one node in the supply chain network launched the knowledge sharing, knowledge reaches to the enterprises of knowledge received through certain channel. The receiver digests and absorbs knowledge, and this process of digestion and absorption is that tacit knowledge and explicit knowledge mutual transformation and deepening process. After digestion and absorption of the receiver, the enterprise increase the knowledge gain, in addition to complete knowledge innovation at some level. Through the digesting and absorbing knowledge, the enterprises improve their own the level of knowledge, contribute their knowledge in the knowledge sharing process.

![Figure 3. Knowledge sharing mode of enterprises in supply chain network](image)

In order to better understanding knowledge sharing process of the upstream and downstream enterprises in the supply chain, the Figure 2 shows the one-way knowledge flow of knowledge sharing in the supply chain enterprises. The enterprise which provides the knowledge (manufacturer) first conducts the knowledge expression according to collecting knowledge, and then encodes knowledge which the manufacturer is willing to share through the knowledge sharing channel. Knowledge is received by the receiver (Supplier) through the process of knowledge transmission. The receiver digests new knowledge received, and based on their own knowledge structure; it is the important symbol of understanding knowledge to express new knowledge received. In this process, the receiver must communicate with the provider repeatedly. Combining its own knowledge with the knowledge received, the receiver utilize the knowledge received, and knowledge utilization is the essence of the knowledge innovation.
conditions, hoping to get rewards without sharing knowledge.

B. Applicability of the Evolutionary Game Theory

The evolutionary game is based on the classic game theory [18-20] and the biological evolution. The game participants are the bounded rationality persons, unlike perfect rationality, participants who can’t immediately find the optimal strategy. They need continuous learning and imitation of the optimum strategy. This is a dynamic process of a gradual adjustment, and will reach a state of equilibrium eventually. And once the balance is broken, it is able to back to stability again. The evolutionary game emphasizes the persistence and repetition of game behavior. It is a long-term co-competition between upstream and downstream enterprises in the supply chain. Since the supply chain is affected by the external economy, politics and culture as well as uncertainty of the future, it makes the supply chain partners not completely rational. Moreover, the willingness, costs, and income of knowledge sharing are not the same among different companies. In fact, they affect each other's strategies mutually. This situation is desirable for the analysis of evolutionary game theory, especially in the analysis of the relationships of knowledge sharing of the supply chain enterprises. Hence, the use of an asymmetric replicator dynamics model in the evolutionary game is more appropriate.

III. EVOLUTIONARY GAME MODEL

A. Description of the Problem

(1) There are two participants in the knowledge sharing activities of the supply chain: Manufacturer A, which is the upstream of the supply chain, and Supplier B, which is the downstream of the supply chain. Manufacturer A is dominant in knowledge of the enterprises, while supplier B is weak in knowledge of the enterprises. A and B can represent any two participants of the upstream and downstream enterprises of the supply chain in the knowledge sharing activities.

(2) When the suppliers and manufacturers are participating in the knowledge sharing game, the participating enterprise strategy set is: {sharing knowledge, not sharing knowledge} for each enterprise of A and B.

(3) According to the other side of the knowledge sharing game, they select their own strategy to pursue maximization benefits of their own.

(4) The knowledge sharing process, among the upstream and downstream enterprises of the supply chain, is a process of incomplete information in regard to bounded rationality dynamic decision-making.

(5) When both suppliers and manufacturers choose knowledge sharing, their gains are separated into six parts: the digestion gain which is absorbed by the enterprise, the additional social benefits gained by knowledge sharing, the synergistic gains by knowledge sharing, the incentive gains both members of the supply chain alliance received by knowledge sharing, the knowledge sharing cost, and the knowledge sharing risk. Especially when both the suppliers and the manufacturers choose not to share knowledge and thus all gains are zero.

B. Basic Assumption

(1) When the upstream and downstream enterprises of the supply chain share knowledge, there are two factors influencing the cost, and the first part is spent on sharing the channels. Due to the use of information technology, sharing time and material related costs, it will produce a knowledge sharing cost coefficient as \( D_i \), where \( i = A, B \). The second part is the risk cost of knowledge sharing. The enterprises in the supply chain may lead to its own loss in some advantaged parts by sharing the knowledge, or the enterprises may bear the self-interest loss by the core knowledge stolen by other enterprises. Facing the risk of core competitiveness, one can set the risk factor for knowledge sharing as \( R_i \), where \( i = A, B \). Due to the possibility of upstream and downstream enterprises competing for the same suppliers or customers, the two sides share the same risk coefficient of knowledge, \( R_i = R_{i'} \), denoted as \( R \). Game companies share the same modes and channels, so their knowledge sharing cost coefficients are the same, \( D_A = D_B \), denoted as \( D \).

(2) Knowledge sharing activities among the members of the supply chain, may lead to corporate reputation and image enhancement, thus it can improve the social relationship. The trust relationship in society is a part of the income gained by knowledge sharing, and the social income coefficient of the knowledge sharing is set as \( E \) for the enterprises in the supply chain. At the same time, if the upstream and downstream enterprises of the supply chain share knowledge, the supply chain alliance will reward both sides of the knowledge sharing enterprises, introducing the knowledge sharing incentive coefficient \( I \); if one side (upstream or downstream enterprise) chooses sharing, while the other side chooses not to share the knowledge, then the hitchhiking behavior of the latter enterprise will be punished correspondingly. This may occur when the knowledge sharing enterprise may, through the monopoly, raise the price to restrict development of enterprises [21-23], introducing the punishment coefficient as \( P \).

(3) Knowledge sharing among the enterprise members of the supply chain is as follows. The more knowledge any one party shares, the more benefits the other party will gain from this. Setting the amount of knowledge sharing as \( S_i \), where \( i = A, B \); the degree of trust on both sides of the supply chain directly affects the knowledge sharing intention of enterprise. Setting the degree of trust for both sides as \( \theta \), the actual amount for enterprise knowledge sharing is \( S_i \times \theta \). Additionally, the profits in the knowledge sharing process are also associated with the knowledge absorption capacity. The better absorption capability enterprises could absorb knowledge more efficiently, this sets a firm's absorptive capacity coefficient as \( G_i (i = A, B) \).

(4) Due to the synergistic effect of knowledge sharing, the upstream and downstream enterprises’ members of
the supply chain making the benefits of knowledge utilization far outweigh the benefits of enterprises which use it independently. Due to fact that supplies chain enterprises are in the upstream and downstream of the business process with a natural cooperation motivation, knowledge sharing can improve the level of enterprises in the supply chain and reduce the unit product cost. The premise is that both sides share the knowledge, setting the synergy effect coefficient as $\beta$.

C. The Establishment for a Model of the Evolutionary Game

According to the description of problems and the basic assumptions above, we build the theoretical models of the asymmetrical evolutionary game for the enterprises in upstream and downstream of the supply chain and get the following knowledge-sharing payoff matrix of the game theory:

$$Q_{A1} = y \cdot (G_A \cdot \theta \cdot S_B + \beta \cdot S_A + E - D \cdot \theta \cdot S_A - R \cdot \theta \cdot S_A + I \cdot S_A) + (1 - y) \cdot (E - D \cdot \theta \cdot S_A - R \cdot \theta \cdot S_A)$$

(1)

The expected gain of manufacturer A not to share knowledge is:

$$Q_{A2} = y \cdot G_A \cdot \theta \cdot S_B - P \cdot S_B + (1 - y) \cdot 0$$

(2)

The average expected gain of manufacturer A is:

$$Q_A = x \cdot Q_{A1} + (1 - x) \cdot Q_{A2}$$

(3)

Then, the replicator dynamics equation of manufacturer A is:

$$M(x) = \frac{dx}{dt} = x(Q_{A1} - Q_A) = x\left[Q_{A1} - x \cdot Q_{A1} - (1 - x) \cdot Q_{A2}\right]$$

(4)

To obtain the stable point of the replicated dynamic equation, according to the stability theorem for differential equations, $M(x)$ must be equal to 0 ($M(x) = 0$) and $M'(x)$ is less than 0 ($M'(x) < 0$). According to $M(x)$ is equal to 0, we can get $x^* = 0$, $x^* = 1$, or $y = \frac{(D + R) \cdot \theta \cdot S_A - E}{\beta \cdot S_A + I \cdot S_B + P \cdot S_B}$.

For manufacturer B, the average expected gain of manufacturer B is:

$$Q_B = y \cdot Q_{B1} + (1 - y) \cdot Q_{B2}$$

(5)

$$Q_{B1} = x \cdot (G_B \cdot \theta \cdot S_A + \beta \cdot S_B + E - D \cdot \theta \cdot S_B - R \cdot \theta \cdot S_B + I \cdot S_B) + (1 - x) \cdot (E - D \cdot \theta \cdot S_B - R \cdot \theta \cdot S_B)$$

(6)

$$Q_{B2} = x \cdot (G_B \cdot \theta \cdot S_A - P \cdot S_A) + (1 - x) \cdot 0$$

(7)

In which, $Q_{B1}$ and $Q_{B2}$ represent the expected gain of manufacturer B sharing knowledge or not sharing knowledge, respectively.

The replicator dynamics equation of manufacturer B is:

$$M(y) = \frac{dy}{dt} = y \cdot (Q_{B1} - Q_B)$$

$$= y \left[Q_{B1} - y \cdot Q_{B1} - (1 - y) \cdot Q_{B2}\right]$$

$$= y(1 - y) \left[\frac{x \cdot \beta \cdot S_B + x \cdot I \cdot S_B + E}{-D \cdot \theta \cdot S_B - R \cdot \theta \cdot S_B + P \cdot x \cdot S_A}\right]$$

(8)

According to $M(y) = 0$, we can get $y^* = 0$, $y^* = 1$, or $x = \frac{(D + R) \cdot \theta \cdot S_B - E}{\beta \cdot S_B + I \cdot S_B + P \cdot S_B}$.

D. The Evolutionary Stable Strategy and Dynamic Evolutionary Process

It can be obtained from the replicated dynamic equation of manufacturer A:

When $y = \frac{(D + R) \cdot \theta \cdot S_B - E}{(\beta + I) \cdot S_A + P \cdot S_B}$, then $M(x) = 0$, they are stable for all x.

When $y > \frac{(D + R) \cdot \theta \cdot S_B - E}{(\beta + I) \cdot S_A + P \cdot S_B}$, order that $M(x^*) = 0$, $M'(x^*) < 0$, then $x^* = 1$ is an evolutionary stable state; $M'(x^*) = 0$, then $x^* = 0$ is an evolutionary stable state.

It can be obtained from the replicated dynamic equation of supplier B:

When $x = \frac{(D + R) \cdot \theta \cdot S_B - E}{\beta \cdot S_B + I \cdot S_B + P \cdot S_A}$, $M(y) = 0$, then they are stable for all y.

When $x > \frac{(D + R) \cdot \theta \cdot S_B - E}{\beta \cdot S_B + I \cdot S_B + P \cdot S_A}$, $y^* = 1$ is an evolutionary stable state; $x < \frac{(D + R) \cdot \theta \cdot S_B - E}{\beta \cdot S_B + I \cdot S_B + P \cdot S_A}$, $y^* = 0$ is an evolutionary stable state.
From the above analysis, it can be drawn that there were five local equilibrium points: (0, 0), (0, 1), (1, 0), (1, 1), (D + R) θ · Ṡ y - E \( \beta \cdot S_y + I \cdot S_y + P \cdot S_A \) - (D + R) θ · Ṡ y - E \( \beta \cdot S_y + I \cdot S_y + P \cdot S_A \). The fifth local equilibrium must satisfy the condition as: (D + R) θ · Ṡ y - E \( \beta \cdot S_y + I \cdot S_y + P \cdot S_A \) and (D + R) θ · Ṡ y - E \( \beta \cdot S_y + I \cdot S_y + P \cdot S_A \) are all in the range (0, 1).

According to the method proposed by Friedman [24-25], the local stability of the Jacobi matrix of the system is to analyze the stability of the equilibrium point of the system’s evolution. According to the replication dynamic equations of the supplier and the manufacturer, the Jacobi matrix of the system is:

\[
J = \begin{bmatrix}
\frac{\partial M(x)}{\partial x} & \frac{\partial M(x)}{\partial y} \\
\frac{\partial M(y)}{\partial x} & \frac{\partial M(y)}{\partial y}
\end{bmatrix}
\]

(9)

The value of Determinant J is:

\[\text{det } J = \frac{\partial M(x)}{\partial x} \frac{\partial M(y)}{\partial y} - \frac{\partial M(x)}{\partial y} \frac{\partial M(y)}{\partial x}\]

(10)

The determinant of the trace is:

\[\text{tr} J = \frac{\partial M(x)}{\partial x} + \frac{\partial M(y)}{\partial y}\]

(11)

When \(\text{det } J > 0\) , at the same time \(\text{tr } J < 0\) , the equilibrium point is in a locally steady state. Analysis is shown in the following table.

From table 1, 5 local equilibrium points of the above, points A and D are locally stable. We can draw the conclusion that the evolutionary stable strategy that the suppliers and manufacturers both select the knowledge sharing strategy or don’t both select the knowledge sharing strategy. In addition, there were two unstable points: points B and C, and a saddle point Q. Figure 2 shows the asymmetric evolutionary game process of the supply chain’s upstream and downstream enterprises.

<table>
<thead>
<tr>
<th>Equilibrium point</th>
<th>Det J symbol</th>
<th>tr J symbol</th>
<th>Partial Stable point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(x=0, y=0)</td>
<td>&lt;0</td>
<td>&lt;0</td>
<td>Stable point</td>
</tr>
<tr>
<td>B(x=1, y=0)</td>
<td>&gt;0</td>
<td>&gt;0</td>
<td>Unstable point</td>
</tr>
<tr>
<td>C(x=0, y=1)</td>
<td>&gt;0</td>
<td>&gt;0</td>
<td>Unstable point</td>
</tr>
<tr>
<td>D(x=1, y=1)</td>
<td>&gt;0</td>
<td>&gt;0</td>
<td>Stable point</td>
</tr>
<tr>
<td>Q(x= x̄, y= ȳ)</td>
<td>&lt;0</td>
<td>0</td>
<td>Saddle point</td>
</tr>
</tbody>
</table>

As you can see from Figure 2, the broken line connecting the two unstable points, B and C, and saddle point Q represents the different critical line of the evolutionary game with suppliers and manufacturers. The area of I composed by graph ABQC is \(H_A\), and the area of \(\Pi\) composed by graph QBFC is \(H_B\). \(H_A\) and \(H_B\) represent the probability of their both not sharing knowledge and both sharing knowledge, respectively.

In the area of \(I\), the evolutionary game converges with point A; both the suppliers and the manufacturers don’t share knowledge; In the area of \(\Pi\), the evolutionary game converges to point F, and both the suppliers and the manufacturers share knowledge. The evolutionary game of the enterprises in the supply chain’s upstream and downstream converges to the different equilibrium points with the change of point Q in Figure 2. Point Q is the threshold value of the change within the system’s evolutionary properties. A small change in original state will affect the final results of the evolution of the system. The areas I of \(\Pi\) and determine the direction of the development of evolutionary results.

IV. MODEL PARAMETERS ANALYSIS AND KNOWLEDGE SHARING STRATEGY

A. Model Parameters Analysis of Knowledge Sharing Evolutionary Game

From Figure 2, we know that graphic area of ABQC is:

\[
H_A = \frac{1}{2} \left[ \frac{(D + R) \cdot \theta \cdot S_y - E}{\beta \cdot S_y + I \cdot S_y + P \cdot S_A} + \frac{(D + R) \cdot \theta \cdot S_y - E}{\beta \cdot S_y + I \cdot S_y + P \cdot S_A} \right]
\]

(12)

\[
H_B = 1 - S_A
\]

(13)

According to the analysis of the expression of \(H_A\) and \(H_B\), it can be drawn that the main factors affecting the area I include: cost coefficient of knowledge sharing \(D\). Risk factor of knowledge sharing \(R\), incentive coefficient of knowledge sharing \(I\) and punishment coefficient \(P\), the amount of knowledge sharing for both sides of game \(S_A\), \(S_B\), the synergy effect coefficient of knowledge sharing \(\beta\) and the social relationship benefit coefficient of knowledge sharing \(E\) and the coefficients which influence the critical value of Q are discussed.

(1) Cost coefficient of knowledge sharing \(D\). We can know that from the expression of area I, the smaller \(D\)
is, the larger the area of $H_A$ is, and the more probability for the system convergence to point F. If you want to ensure that both suppliers and manufacturers share knowledge smoothly, the cost should be reduced as much as possible, especially in factors which affect knowledge sharing.

(2) Risk coefficient for knowledge sharing $R$. It can be seen from the expression of regional $I$, $H_I$ is monotone decreasing function of $R$. The smaller $R$ is, the larger $H_A$ area is. The system prefers to share knowledge with both sides.

(3) Incentive coefficient of knowledge sharing $I$ and punishment coefficient $P$. It can be seen from the expression of critical points F that the greater $I$ and $P$ are, the higher the probability of the system’s evolution tending to point F is. When the area $H_A$ is larger, the system prefers to share knowledge with both sides.

(4) The amount of knowledge sharing for both sides of game $S_A$, $S_B$. In this paper, the shared knowledge of the core enterprises (manufacturers, enterprise of advantaged knowledge) of the supply chain is far greater than that of the non-core enterprises (suppliers). If the ratio $\frac{S_A}{S_B}$ is higher, which means, the gap between both in knowledge sharing is bigger. It can be seen that the expression of the horizontal and vertical coordinates of the saddle point and Figure 2. When the larger $H_A$ is, the smaller $H_B$ is. So the probability of systems converging to F(1,1) is smaller. Meanwhile, the probability of both sides selecting the knowledge sharing is smaller.

(5) The synergy effect coefficient of knowledge sharing $\beta$. The bigger the synergy effect coefficient is, the closer point Q is to point A, and then the area $\Pi$ is larger. The probability of the evolutionary system tending to point F is greater, so the probability of both sides selecting the strategy (sharing, sharing) is greater.

(6) Social relationship gain coefficient of knowledge sharing $E$. It can be seen from the results, the variables $E$ is inversely proportional to the ABQC graphics area $H_A$. As the variable $E$ increased, the $H_A$ decreased. So the probability of both sides selecting the strategy (sharing, sharing) is greater.

**B. The Promotion of Knowledge Sharing Measures In The Upstream and Downstream Enterprises of the Supply Chain**

According to the model analysis, the paper offers the following strategies to improve knowledge sharing among the upstream and downstream enterprises.

(1) Reduce the knowledge sharing channel costs and risk costs in the upstream and downstream enterprises. As can be seen from the constructed model above, the supply chain enterprises should strive to reduce the impact of time and material cost factors through the establishment of the supply chain knowledge base. They should also enhance communication to reduce distance barriers and establish closer alliances. Additionally, they should be less concerned with the losses of advantage resulting from knowledge sharing and should foster an atmosphere of cooperative knowledge sharing.

(2) Increase the social capital gains of knowledge sharing in the upstream and downstream enterprises. Through social capital gains, trust and respect can be gained by other members in the supply chain. This is conducive to enhancing corporate image. By increasing emphasis on knowledge sharing behaviors, enterprises increase efforts to protect intellectual property and create a good range of knowledge sharing.

(3) Establish incentive mechanisms and punishment mechanisms in the upstream and downstream enterprises of the supply chain. The supply chain alliance enhances brand image and the reputation of enterprises through the incentives in the knowledge sharing enterprise or through the honor granted to knowledge sharing enterprises. Moreover, when establishing strict punishment mechanisms for free-riding phenomenon, the punishment for the speculators needs to be more than the gains to improve knowledge sharing initiatives in the upstream and downstream enterprises of the supply chain.

(4) Diminish the gap between the amount of knowledge sharing of the upstream and downstream enterprises of the supply chain. As can be seen from the constructed model above, the level of knowledge gaps are closely linked with whether the supply chain companies have employed knowledge sharing strategies. The smaller the gap is, the better the enterprises are both able to promote knowledge sharing. In practice, when choosing knowledge sharing partners, one should establish a good cooperative mechanism and should select knowledge sharing partnerships with those who have the same business background, and a similar economic business model. One should also establish and improve the supply chain training system to reduce the knowledge gap between the supply chains.

(5) Establish supply chain knowledge sharing systems. With the construction of IT infrastructure, the knowledge storage and transfer between enterprises in the supply chain will become more effective. It would not only reduce the cost of inter-firm knowledge sharing and would have a significant impact on knowledge sharing behavior, but it can also promote knowledge-based collaboration and improve revenue sharing.

(6) Improve learning ability. Learning capabilities include the abilities to both absorb and integrate knowledge. The stronger the knowledge absorptive capacity is, the higher the speed of conversion and efficiency is when the companies absorb new knowledge. The stronger the knowledge integration capability is, the more effective the knowledge is disseminated. In reality, enterprises in the supply chain need to focus on fostering a learning culture, improving the quality of staff, increasing investment in research, establishing an ideal integration mechanisms of knowledge of the supply chain to accelerate the speed of knowledge integration and knowledge sharing efficiency.

(7) Create a culture of knowledge sharing in the supply chain. Corporate culture has an effect on the guidance,
inspiration and cohesion of inter-enterprise knowledge sharing. A knowledge sharing culture can promote exchanges between enterprises. And hence a cooperative win-win way of thinking is formed, and the conflicts between enterprises are reduced. The knowledge sharing culture adjusts the organizational structure of the supply chain between enterprises so that the organizational structure goes in a flat, flexible direction. It establishes corporate alliances between enterprises in the supply chain, collects knowledge across the enterprise team, forms the atmosphere of knowledge sharing and cooperation, thereby increases the overall competitive advantage of the supply chain.

V. CONCLUSION

This paper, using evolutionary game theory, analyzes the knowledge sharing among the upstream and downstream enterprises of the supply chain (suppliers and manufacturers), builds the supply chain asymmetric upstream and downstream enterprises evolutionary game model, and simulates the dynamic evolution game process of the supply chain. By building the model and solving the model, an evolutionary stable strategy of supplier and manufacturer is (not sharing, not sharing) and (sharing, sharing). And the analysis of the related factors that affect the upstream and downstream enterprises of the supply chains is made. The results show that selecting knowledge sharing strategy in the upstream and downstream enterprises are affected by the factors: the cost coefficient of knowledge sharing, the risk coefficient of knowledge sharing, the gap between the amount of knowledge sharing of enterprises, which have significant negative correlation to selecting knowledge sharing strategy in the upstream and downstream enterprises; the coefficient of gains in social relationships, the synergistic effect coefficient of knowledge sharing, the incentive and punishment factor of knowledge sharing, which have strong positive correlation to selecting knowledge sharing strategy. Finally, on this basis, this paper proposes the measures for promoting the knowledge sharing of the upstream and downstream enterprises of the supply chain.

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REFERENCES


**Hengshan Zong** was born in Henan Province, China in 1986. He received his M.S. in communication Information and System from Taiyuan University of Technology, Shanxi, China, in 2011. He is currently a Ph. D candidate at School of Economics & Management, Beihang University. His research interests are Knowledge Management and Product Development Management, Cellular Manufacture and so on.

**Guozhu Jia** is a professor in School of Economics and Management, Beihang University, Beijing, China. His research interests include supply chain management, process management, human resource management, operation strategy. He is a member of China system simulation society, the director of China human ergonomics society, and the senior visiting scholar at Central University of Technology in France.

**Feng Jin** was born in Beijing city, China. She is currently an undergraduate at School of Economics & Management, Beihang University. Her research interests are Industrial engineering, supply chain management, process management and so on.

**Jili Kong** was born in Tianjin city, China in 1982. He received his Ph.D in management science and engineering from Beihang University, Beijing, China, in 2014. His research interests are Operation and Production Management, Process management, Industrial engineering.