The Evolutionary Game Analysis of Independent Innovation and Imitation between Knowledge-based Enterprises

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Abstract
By applying replicate dynamic formula, this paper constructs an evolutionary game model, analyzing the strategic choices of independent innovation and imitation between enterprises in their cooperative innovation process. The result suggests that strategic choices are determined by their own knowledge, technology and capital stock. When innovation cost is higher and imitation cost is lower, enterprises will gradually adjust their innovation strategies, and tend to choose imitate strategy through incessant imitation and learning. Therefore, the government should encourage independent innovation, providing funding support for independent innovation to the enterprises, creating a favorable policy environment and legal environment, improving intellectual property protection in order to appropriately increase imitational cost.

1. Introduction
The concept of “innovation” was proposed by Joseph Alois Schumpeter, an Austrian-born American economist. He believed that, the innovation was actually, to bring the new inventions into production system by entrepreneurs, then to realize a new portfolio of production factors and conditions, and finally reap the potential excessive profit (Schumpeter, 1939). Since the Innovation theory was raised by Schumpeter, innovation has been commended unprecedentedly and become the core of enterprise development strategy (Veugelers, 1999). Moreover, innovation has turned into the soul of national and regional economic development promoting. R. Nelson (Nelson, 1967) considered that diversification could make use of innovations more effectively, more diversification intensity, more R&D strength. Knowledge-Driven model (Romer, 1990) supposed technological progress performed as the increment of semi-finished product species. Romer thought one intermediate inputting marginal product was unrelated with the quantity of others (Romer, 1999). There are many kinds of recognized innovation models as the continuously enriched and development of innovation theory, in which the independent innovation model is the most important. Independent innovation is a creative activity relative to technology introduction and imitation, which is the process to realize the value of new products on the basis of unique core technology with independent intellectual property. That means, the core technology required for innovation derived from the inner technological breakthrough and obtained through self-reliance and independent R&D, which disengaged the technology introduction and imitation from dependence on technologies obtained from outside. In essence it is to firmly grasp the initiative of key link to innovation and the ownership of core technology. Independent innovation is the key to achieve monopoly position and gain competitive superiority, and it is the most significant for economic development and national security. Independent innovation put forward higher requirements to innovation subject, such as fully reinforced and powerful ability to tolerate innovation failure risk.
However, some knowledge-based enterprises such as information service industry, the companies within the industry have generally problems go against independent innovation low agglomeration degree, comparatively small scale and less competitive. Technology introduction and imitation will prevalent if it is not actively guided. Innovation and imitation are the general behavior strategies adopted by companies in innovative activities. On the one hand, independent innovation enterprises could be dominant and gain the monopoly position, while the imitation companies could reduce R & D costs, lower risks and increase efficiency by imitation. On the other hand, the flourished imitation will certainly dampen the companies’ enthusiasm to innovation independently, which leads companies are reluctant to carry out innovative development. The cutthroat competition among enterprises caused by prevailing “free-rider” behavior, is sufficient to result in the stagnancy of creative development and cumulative excess, as well as the cluster shrink. Pang and Liu (2003) has built the game model of independent innovation and imitation pattern from the point of economic benefit, and thought it’s a significant strategic choice for China’s adopting technology innovation copy mode. Liu and Shi (2007) think that, on the basic of Roomer’s Leader-Followers model, the game model of Innovator-Imitator has been designed to derive the determinant of enterprises’ independent innovation and imitation probability, and do the economic analysis about strategic decision on independent innovation and imitation. The imitation could obtain kinds of advantages better than the innovation, as low risk, high efficiency, low-cost advantage and market dominance.

When enterprise makes decision on innovation or imitation, the behavioral process in fact is a learning process of evolution. The optimal strategy of game members is to copy and improve the past most favorable strategy for themselves and others. Furthermore, both sides have tended to be a stable strategy through a long-term of imitation and improvement. The evolutionary game theory is a new theory that combines game theoretical analysis and dynamic evolutionary process analysis, which originates from behavioral ecology. It is from bounded rationality individuals, uses group behavior as subject investigated and reasonably explains the evolutionary process of biological behavior (J, 1974). For this reason, this paper applies the evolutionary game model to analyze the innovation and imitation behavior of companies in cluster innovation network, to realize the link between innovation and imitation from mechanism, moreover, to find the way of encouraging more enterprises to precede independent creation.

2. Basic Assumptions & Modeling
Game parties: In this paper, game parties are the enterprises in cluster innovation network, and the both parties are satisfied to the bounded rationality. In addition, we suppose the information is symmetry to both sides for the simple calculation.
Game strategy: To either game party, the behavior strategy could be innovation or imitation, so the strategy choosing spaces are both (Innovation, Imitation).
Pay-off matrix: The pay-off matrix of both parties is shown as Table 1

<table>
<thead>
<tr>
<th>Enterprise A</th>
<th>Enterprise B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation</td>
<td>Innovation</td>
</tr>
<tr>
<td>Enterprise A</td>
<td>$m-r$, $m-r$</td>
</tr>
<tr>
<td>Imitation</td>
<td>$p-c$, $m-r+c$</td>
</tr>
</tbody>
</table>

Table 1 The Game Pay-off matrix of Innovation Imitation
The Pay-off matrix’s meaning:

1. When both parties select imitation which means they don’t innovate, the game members cannot reap innovation benefits. Here “0” is the assumed profit of Enterprise A and B.

2. When Enterprise A choose innovation and B is imitation, A’s net income is \( m - r + c \) in which \( m \) presents A's innovation income at this moment. \( r \) denotes A’s innovate R&D costs, such as fund input, human resource support and material consumption. \( c \) denotes A's costs of intellectual property from imitation enterprises. Correspondingly, Enterprise B’s net profit is \( p - c \). 

3. According to the symmetry, when Enterprise A makes a choice of imitation and B is innovating, the benefits of both sides is \( p - c \) and \( m - r + c \) respectively.

4. When both parties decide to innovate, considering the diversity of their innovation, either party isn’t having the revenue loss due to the existence of the other one, and both of them are only to undertake own innovate R&D costs \( r \), therefore the profit of A&B are \( m - r \).

Behavior strategies adoption probability: at game’s primary stages, Enterprise A's probability to choose innovation strategy is supposed to be \( x \), then, the probability of imitation strategy is \( 1 - x \). Enterprise B probability to select innovation strategy is \( y \) and of imitation strategy is \( 1 - y \). 

3. Analysis of Evolutionary Game Model
According to above assumptions and Pay-off matrix, the expected revenue of Enterprise A’s adopting innovation strategy is:

\[
U_{A1} = y(m - r) + (1 - y)(m - r + c)
\]

The expected revenue of A’s imitation strategy is:

\[
U_{A2} = y(p - c)
\]

So Enterprise A’s average expected revenue is:

\[
\overline{U}_A = xU_{A1} + (1 - x)U_{A2}
\]

In a similar way, we can get Enterprise B’s expected revenue of adopting innovation strategy, imitation strategy and average expected revenue is respectively:

\[
U_{B1} = x(m - r) + (1 - x)(m - r + c)
\]

\[
U_{B2} = x(p - c)
\]

\[
\overline{U}_B = yU_{B1} + (1 - y)U_{B2}
\]

Based on the replicator dynamical equation of evolutionary game equilibrium:

\[
dx/dt = x(U_i - \overline{U})
\]

Enterprise A and B’s replicator dynamical equations are:

\[
F(x) = dx/dt = x(U_{A1} - \overline{U}_A) = x(1 - x)(m - r + c - py)
\]

\[
F(y) = dy/dt = y(U_{B1} - \overline{U}_B) = y(1 - y)(m - r + c - px)
\]

On the principle of differential equation’s stability and evolutionarily stable strategies’ characteristic,
evolutionary game’s steady state has to meet the condition: \( F(x^*) = 0, F(x^*) < 0 \). Then we get this following table:

<table>
<thead>
<tr>
<th>Equilibrium point</th>
<th>( F(x^<em>) &amp; F(y^</em>) )’s value</th>
<th>( F(x^<em>) &amp; F(y^</em>) )’s value</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x = 0, y = 0 )</td>
<td>0, 0</td>
<td>( m-r+c, m-r+c )</td>
<td>undetermined</td>
</tr>
<tr>
<td>( x = 0, y = 1 )</td>
<td>0, 0</td>
<td>( m-r+c-p, -(m-r+c) )</td>
<td>undetermined</td>
</tr>
<tr>
<td>( x = 1, y = 0 )</td>
<td>0, 0</td>
<td>( -(m-r+c), m-r+c-p )</td>
<td>undetermined</td>
</tr>
<tr>
<td>( x = 1, y = 1 )</td>
<td>0, 0</td>
<td>( -(m-r+c-p), -(m-r+c-p) )</td>
<td>undetermined</td>
</tr>
<tr>
<td>( x = (m-r+c)/p )</td>
<td>0, 0</td>
<td>0, 0</td>
<td>saddle point</td>
</tr>
</tbody>
</table>

Case 1: When \( p > m-r+c > 0 \), from Table 2 we know there are two \((0, 1)\) and \((1, 0)\) of evolutionary game system’s evolutionarily stable strategies (ESS), that is (Imitation, Innovation) and (Innovation, Imitation). The game analysis is shown as Fig. 1:

![Fig. 1 the phase diagram of game analysis under case 1](image)

From the Fig. 1 we can see that, when system’s original state locates in zone C, to wit the probability of Enterprise A’s selecting innovation is greater than B’s, Enterprise A’s benefit which be \( m-r+c > 0 \), while B is \( p-c \). Back to earth, the patent fee paid due to Enterprise A’s imitation is usually less than profit, therefore we can consider that \( p-c > 0 \). Obviously, to Enterprise A carrying on innovation is not only profitable, but can also collecting patent fee from B as well as accessing to technology monopoly position. To Enterprise B, to imitate A’s technology is not just save the cost of R&D and get rid of the risk of innovation. Furthermore, it is still profitable after paying appropriate patent fee. As a result, by continuing imitation and studying, Enterprise A will choose independent innovation strategy, while B select imitation strategy. Finally, evolutionary game system will converge to evolutionarily stable strategy \((1, 0)\). When system’s original state locates in zone D, we just receive the opposite conclusion.

Case 2: When \( p > 0 > m-r+c \), from Table 2 we know evolutionarily stable strategy (ESS) of
evolutionary game system is \((0, 0)\), that is (Imitation, Imitation), and the game analysis is shown as Fig. 2:

```
\begin{align*}
X & \quad (1, 1) \\
0 & \quad y
\end{align*}
```

Fig. 2 the phase diagram of game analysis under case 1

From Fig. 2, wherever the system’s original state is, the profit of company choosing independent innovation strategy is \(m - r + c < 0\), while that of company selecting imitation strategy is \(p > 0\) in the case of not paying patent fee. Apparently, it is more favorable to pick imitation. So after constant imitation and learning, both Enterprise A and B will select imitation strategy at last, that is evolutionary game system is converge to evolutionarily stable strategy \((0, 0)\). The reality is that, the higher innovating costs of enterprises in the cluster innovation network enable imitation strategy to be more favorable. It makes companies being inclined to the imitation strategy, cutting the throat of their innovation ability and lowering the enthusiasm of independent innovation of enterprises. Moreover, the prevailing “free-rider” behavior will cause the stagnancy of creative development and cumulative excess, as well as the cluster shrink. Therefore, for one thing government should encourage enterprise’s independent innovation, provide capital funds as well as required policies and laws environments for companies to carry on independent innovation. on the other side, great importance should be attached to intellectual property rights and increase imitation costs. Through joint efforts of both sides, \(r\) will be less while \(c\) is increasing, then creative ventures’ revenue is growing and imitating ones is decreasing. It prompts the whole cluster innovation network to transform to the direction of the virtuous circle.

Case 3: When \(m - r + c > p > 0\), the saddle point \(((m - r + c)/p, (m - r + c)/p) > (1, 1)\) is pointless. The reality is that, it’s impossible of all companies choosing innovation strategy. On the one hand, the profit of selecting independent innovation strategy is more than imitation strategy, and the enterprises with abundant knowledge technology accumulation and strong capital strength will choose the self-renovation strategy. On the other hand, though the benefit of imitation strategy is less than independent creation strategy, it is still be plus after deducting the patent charges. So some business without self-creative ability will choose imitation strategy according to their needs, and this is reducing repeating innovating development and then save social resource.

4. Conclusions and recommendations

By applying replicate dynamic formula, we construct an evolutionary game model, and analyses the strategic choices of independent innovation and imitation between enterprises in their cooperative
innovation process. The result suggests that strategic choices are determined by their own knowledge, technology and capital stock. It has a relatively high probability for the enterprises with strong power to choose independent creation. And also balancing the factors of innovation benefits and imitation costs, the enterprises tend to carry on self-innovation. The weaker businesses are inclining to choose opposite strategy. When innovation cost is higher and imitation cost is lower, enterprises in the cluster innovation network will gradually adjust their innovation strategies, and tend to choose imitate strategy through incessant imitation and learning, and the prevailing “free-rider” behavior will cause the decline of whole innovating capacity and cluster shrinking. In the knowledge-based industrial clusters, part of companies will stress independent innovation and the other part will mainly on imitation. In the cluster, they build a good interaction with each other, and realize the rational distribution of innovating resource, reducing repeating innovating development as well as saving social resource. Therefore, on the one hand, the government should encourage independent innovation, providing funding support for independent innovation to the enterprises, creating a favorable policy and legal environment, improving intellectual property protection in order to appropriately increase imitational cost, and then promoting the whole cluster innovation network to transform to the direction of the virtuous circle. On the other hand, government should play a full role of the advantage of concentrating local universities and scientific research institution, and actively promote the independent innovation in forms of cooperative innovation between industry, college and institute (Gao and Gao, 2010).

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