Research on Evolution Path of Innovation Chain of Nuclear Power Industry-based on Innovation Synergy

Yu-qiong LI, Bei-bei ZHAO, Yang LI, Yuan YAN, Xiao-long FU and Kai CHEN*

College of Management, University of South China, Hengyang, Hunan, China

*Corresponding author

Keywords: Nuclear power industry innovation chain, Synergy model, Evolution path.

Abstract. This paper was based on the perspective of innovation synergy, by analyzing the synergetic evolution mechanism and characteristics of the industry chain and innovation chain, built order degree model of industrial chain and innovation chain and the synergy degree model of composite system. And based on the relevant data from 2009 to 2015, the synergetic degree and evolution path between the industrial chain and the innovation chain were empirically analyzed by using the synergy degree model of composite system. The results show that the overall level of innovation synergy of nuclear power industry is low and the fluctuation trend is presented. Among them, the number of technology introduction and the strength of investment in scientific research are the key factors that affect the innovation coordination system. Finally, in view of the current situation of innovation synergy, the nuclear power industry innovation chain in our country, it provides policy recommendations for the macroeconomic regulator.

Introduction

Industrial innovation is the impetus to the development of the whole economy. At present, the nuclear power industry is developing rapidly, but its innovation ability is weak. The synergy between the nuclear power industry chain and the innovation chain is not high, presenting a two-skinned phenomenon. The new products and technologies provided by the innovation chain can’t be used effectively by industrial chain, the innovation chain also lacks the impetus to nurture the industrial chain. However, in order to improve the innovation ability of the nuclear power industry, how to improve the innovation ability, reduce the waste of innovation resources and realize the cooperative development of nuclear power industry innovation is a problem that needs to be solved urgently at present.

With the increasing prominence of these problems, scholars have also gradually increased their research on the industrial innovation chain. The concept of industrial innovation chain was first proposed by Malerba and Breschi. It is believed that the industrial innovation chain can be defined as the set of activities of companies that produce industrial products \(^1\) \(^2\) (Malerba and Breschi, 2001). The key to the industrial innovation chain is cooperative innovation networks \(^3\) (Jin Chen, 2012). Bin-bin Yu (2011) discusses the relationship between industrial chain and innovation chain from the angle of industrial cluster. Upstream enterprises provide products and services for downstream enterprises. The cluster of enterprise benefits sharing, invulnerability and mutual competition, for enterprise innovation to create power. Cluster innovation creates the possibility for the integration of the industrial chain and the innovation chain \(^4\). To realize the double chain fusion, we should build up the open innovation network mechanism of the research and development, put forward the basic study, the middle-end technology service, the back-end achievement transformation and the project industrialization to form a complete chain, so that the industrial chain and the innovation chain can be integrated \(^5\) (Rui-bo Zhu, 2012).

This study holds the view that the industrial chain and the innovation chain are two chains with different development connotations, and have different development elements. The two chains interact with each other to form a complete network system for development. The system is
composed of elements. Elements interact with each other, thus forming the industrial innovation chain.

**Evolution Index System and Model Construction**

**Evolution Index System**

According to the synergetic theory, this paper divides the industrial innovation chain into two major subsystems: industrial and innovation chain. The evaluation indicator system is shown in Table 1:

<table>
<thead>
<tr>
<th>Evaluation index</th>
<th>Indicator explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>New fixed asset rate</td>
<td>Reflect the ability of business product updates</td>
</tr>
<tr>
<td>The number of technology imports</td>
<td>Reflect the ability of business development</td>
</tr>
<tr>
<td>Asset turnover</td>
<td>Reflect the efficiency of asset management</td>
</tr>
<tr>
<td>High-skilled worker ratio</td>
<td>Reflect the technological capabilities of enterprises</td>
</tr>
<tr>
<td>Postgraduate education staff ratio</td>
<td>Reflect the investment ability of technological innovation</td>
</tr>
<tr>
<td>R &amp; D personnel ratio</td>
<td>Reflect the investment ability of technological innovation</td>
</tr>
<tr>
<td>R &amp; D expenditure as a percentage of operating income</td>
<td></td>
</tr>
<tr>
<td>Production and research cooperation projects</td>
<td>Reflect the technical innovation support ability</td>
</tr>
</tbody>
</table>

**Model Building**

Assuming that the order parameter variables in the process of co-evolution of the nuclear power industry innovation chain are $e_i = (e_{1i}, e_{12}, \ldots e_{1n}), n \geq 1$, $\beta_{1i} \leq e_{1i} \leq \alpha_{1i}, i \in [1, n]$. In this paper, the order variable of the nuclear power industry chain system can be regarded as the evaluation index of the industrial chain. Without loss of generality, assuming that $e_{11}, e_{12}, \ldots e_{ij}$ is a slow-order parameter, the bigger the value is, the higher the order of the system is, and the smaller the value is, the lower the order of the system is; $e_{1j+1}, e_{1j+2}, \ldots e_{1n}$ are fast-galloping parameters. The larger the value is, the lower the order of the system is. The smaller the value is, the higher the order of the system is. Therefore, there is the following definition:

**Definition 1** The order degree of the $e_{1j}$ of the sequence parameter component of the industrial chain:

$$u_i(e_{1j}) = \begin{cases} e_{1i} - \beta_{1i} & , i \in [1, j] \\ \alpha_{1i} - \beta_{1i} & , i \in [j + 1, n] \end{cases}$$

(1)

From the definition above, we can see that the larger the value of $u_i(e_{1i}) \in [1, n]$, the greater the "contribution" of $e_{1i}$ to the order degree of the industrial chain. It should be pointed out that in practice some $e_{1i}$ values are either too large or too small to be good, but they are best concentrated on certain specific surroundings. Such as $e_{1i}$, it can always be adjusted by adjusting its value interval $[\beta_{1i}, \alpha_{1i}]$, which make its order definition satisfy definition 1.
The overall "total contribution" of order parameter variables $e_{11}$ to the orderliness of the industry chain can be achieved through the integration of $u_1(e_{11})$. However, the "integration" law depends on different combinations of system specific structures. For the sake of simplicity, this paper adopts linear weighted summation method to deal with:

$$u_1(e_1) = \sum_{i=1}^{n} \omega_i \cdot u_1(e_{1i}), \quad \omega_i \geq 0 \quad \text{and} \quad \sum_{i=1}^{n} \omega_i = 1$$

**Definition 2** $U^{1}(e_1)$ is defined as the order degree of the industrial chain.

From definition 2, $u_1(e_1) \in [0, \ 1]$, the greater the $u_1(e_1)$, the greater the contribution of $e_1$ to the orderly chain, the higher the orderliness of the industry chain, the lower the reverse.

Similar to the hypotheses in the industry chain, the same results can be obtained:

**Definition 3** The order degree of $e_{2i}$ for the innovation chain sequence parameter component.

$$u_2(e_{2i}) = \begin{cases} \frac{e_{2i} - \beta_{2i}}{\alpha_{2i} - \beta_{2i}}, & i \in [1, \ j] \\ \frac{e_{2i} - \beta_{2i}}{\alpha_{2i} - \beta_{2i}}, & i \in [j + 1, \ n] \end{cases}$$

**Definition 4** The definition of $u_2(e_2)$ is the order degree of innovation chain.

$$u_2(e_2) = \sum_{i=1}^{n} \omega_i \cdot u_2(e_{2i}), \quad \omega_i \geq 0 \quad \text{and} \quad \sum_{i=1}^{n} \omega_i = 1$$

From definition 4, $u_2(e_2) \in [0, \ 1]$, the larger $u_2(e_2)$, the greater the "contribution" of $e_2$ to the ordered innovation chain, the higher the order of the innovation chain, the lower the reverse.

Suppose that at the initial time (or a certain period of time) $t_0$, the order of the industrial chain is $u^0_1(e_1)$ and the order of the innovation chain is $u^0_2(e_2)$. However, at the moment $t_1$ of the nuclear power industry innovation chain in the evolution process, if the order degree of the industrial chain is $u^1_1(e_1)$, the order of the innovation chain is $u^1_2(e_2)$.

**Definition 5** The following are the degree of innovation synergy in the industrial chain and innovation chain in the nuclear power industry innovation chain:

$$C = \lambda \cdot \sqrt{|u^1_1(e_1) - u^0_1(e_1)| \times |u^1_2(e_2) - u^0_2(e_2)|}$$

Supplement to Definition 5:

① The level of $C$ value represents the level of innovation coordination.

② When the $C$ value is negative, the two sub-chains that represent the industrial innovation chain is uncoordinated and is in the disorderly development process. When the $C$ value is positive, the result is opposite.

③ Innovation coordination is a process of dynamic evolution. It is necessary to grasp the coordination status of the whole chain through the calculation of innovative coordination degree.
Innovation Synergy of Nuclear Power Industry Innovation Chain

This paper uses the data of all NPPs and unlisted companies of 128 companies from 2009 to 2015, financial data from CCER economic and financial databases, innovative input data from Ifind Flush database, patent data from Cathay Pacific. Based on formula (5), the innovation synergy of the 2009-2015 nuclear power industry innovation chain is calculated, the result is as figure1:

![Figure 1. The evolution trend of innovation chain of nuclear power industry innovation.](image)

In 2009-2015, the innovation synergy in the innovation chain of the nuclear power industry was negative in 2011, mainly due to the increased orderliness of the industry chain and the decreasing order of innovation chains, indicating that in 2011, the two subsystems coordinated development. However, the synergies between the two chains started to turn positive in 2012, while the orderliness of both the industrial chain and the innovation chain declined. This indicates that the degree of orderliness is decreasing at the same time. After 2013 the degree of system coordination began to increase gradually.

Evolution Path of Nuclear Power Industry Innovation Chain

According to the theory of system coordination, the degree of coordination is an important index that reflects the coordination and evolution of coordination system quantitatively. The value is between (-1, +1). Table2 shows the correspondence between the coordination degree and the coordination level.

<table>
<thead>
<tr>
<th>Degree</th>
<th>-1~0</th>
<th>0~0.39</th>
<th>0.40~0.69</th>
<th>0.70~1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Non-cooperative</td>
<td>Low coordination</td>
<td>Moderate coordination</td>
<td>High coordination</td>
</tr>
</tbody>
</table>

The path of innovation in the nuclear power industry is divided into four stages, as shown in Table 3:

<table>
<thead>
<tr>
<th>Development stage</th>
<th>Time</th>
<th>Features</th>
<th>The changing trend of innovation Synergy</th>
<th>Nuclear power development</th>
<th>Innovative performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first stage</td>
<td>1955-1975</td>
<td>Non-cooperative</td>
<td>Rise</td>
<td>The initial stage</td>
<td>None</td>
</tr>
<tr>
<td>The second stage</td>
<td>1976-2004</td>
<td>Close to synergy</td>
<td>Slowly rise</td>
<td>Accelerate the development</td>
<td>feeble</td>
</tr>
<tr>
<td>The third stage</td>
<td>2005-2012</td>
<td>synergy</td>
<td>Rise smoothly</td>
<td>Develop fast</td>
<td>General</td>
</tr>
<tr>
<td>The fourth stage</td>
<td>After 2013</td>
<td>Low to moderate coordination</td>
<td>Rise rapidly</td>
<td>Develop at top speed</td>
<td>Strong</td>
</tr>
</tbody>
</table>
The trend of synergetic evolution of nuclear power industry innovation chain is shown in the following figure:

![Figure 2. Co-evolution diagram of nuclear power industry innovation chain.](image)

**Conclusion and Suggestions**

Based on the results and trends of innovation synergy, the following conclusions are drawn: (1) The innovation coordination degree of nuclear power industry is between -0.05161 ~ 0.19652, and the overall level of innovation coordination is low, which belongs to the low level of coordination. (2) The orderliness of the industrial chain and innovation chain gradually increased. The overall trend of development was coordinated and the state was effectively coordinated, and the effective coordination mechanism between the industrial chain and the innovation chain was initially formed. (3) The proportion of technology introduction funds, the intensity of scientific research funding has a great influence on the degree of system orderliness, and they are the key factors that influence the innovation coordination system.

Finally, aiming at the status quo of innovation synergy in the innovation chain of nuclear power industry in our country, the following policy suggestions are provided for macro-control. (1) The government should increase investment in nuclear power innovation and promote the leaping development of nuclear power. The state can provide financial support through market means, encourage banks to reduce lending rates, reasonably relax the loan deadlines and reduce the pressure on repayment of loans by nuclear power companies. In addition, private capital can be encouraged to enter the nuclear power industry, speed up the development of corporate bonds and diversify financing channels for nuclear power, providing multiple sources of funding for nuclear power. (2) Promote coordinated development of internal elements of the nuclear power innovation chain and enhance the level of industrial autonomy, the domestic enterprises should realize the importance of technology sharing, the key technology should be cooperated, especially the foreign monopoly technology, break through the technology monopoly as soon as possible, realize the localization of technology, master the initiative and competitiveness of nuclear power development. (3) Establish a collaborative innovation platform for government, industry, research and development to catch up with academic frontiers. The establishment of innovation alliances between nuclear power enterprises, universities and research institutes will greatly enhance the innovation capability of the nuclear power industry. Innovation alliances establish strict access standards, institutions within the Union to ensure the sharing of benefits. Universities and research institutes should do a good job of technology research and development, and the government and enterprises should make good financial support and the transformation of technological achievements should be owned by the enterprises. Enterprises should do a good job in landing the ground, so that the achievements can be realized in a short period of time and promote a virtuous circle of "research in politics, production and research".
Acknowledgements

This research was financially supported by the National Nature Science Foundation, China (71373113) and Hunan Province Social Science Founds, China (17JD73).

Reference