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Dynamic Mechanism and Innovation Mode of Industrial Development in Resource-based Cities

Dan Liu*, Qian Zhang
School of Management, Heilongjiang University of Science and Technology, Harbin, Heilongjiang, China
*Corresponding Author.

Abstract:

Industrial structural adjustment is the core of the transformation and development of resource-based cities and determines the formation of the urban economic foundation. Resource-based industry dependence is the main feature in the development of resource-based cities, and the main means to get rid of dependence is the introduction of innovative elements.By identifying the driving factors in the formation of industrial advantages, this paper constructs the evolution model of industrial development power from the perspective of technology and system synergy drive, defines the leading elements of industrial development in different life cycle stages,discusses hypercycle structure of self-organizing evolution, and the orderly evolution of the industrial development system to a higher level based on the hypercycle theory. Finally completes form innovation, structural innovation, organizational innovation and regional innovation mode design in the industrial development process of resource-based cities, provides countermeasure support for the transformation and development of resource-based cities.

Keywords*: industrial development; dynamic evolution; innovation model*

I. INTRODUCTION

Scholar Harken proposed the theory of synergy in 1970, which is self-organization theory that studies how multiple subsystems in a composite system form one or some order parameters through the synergy behavior between the sub-systems, thereby promoting the self-ordered evolution of the system structure[1]. In the research on the industrial development system of resource-based cities, innovation collaboration can be seen as a self-organization process in which interaction between technological innovation and system innovation subsystems forms technological innovation and system innovation or both serve as the order parameters and dominate the industrial structure adjustment[2], thereby achieving transformation of resource-based cities. At the same time, in the transformation of resource-based cities driven by power, through hypercycle reaction, the resource-based urban industrial system can evolve to a new orderly state and form a new urban industrial development model.

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II. THE EVOLUTION OF THE DRIVING FORCE FOR THE INDUSTRIAL DEVELOPMENT OF RESOURCE-BASED CITIES

Using the theory of synergy and drawing on the innovation co-evolution model constructed by Professor Xu Qingrui, we construct an industrial innovation co-evolution model for resource-based cities.

Hypothesis: Industrial development of resource-based city only considers two options: technological innovation and institutional innovation. The proportions of the two options are constantly adjusted with changes in the life cycle under different economic environment. The evolution of technological innovation and institutional innovation is a continuous process from urban development growth period, to mature period, decline period and then to the regeneration period.

2.1 The evolution equation of technological innovation and institutional innovation

Suppose that the total innovation input resource in the development of urban industries is $2R$, $2R \geq 0$. Where, the technological innovation input is $r_t(t)$, and the institutional innovation input is $r_i(t)$

There is: $$r_t(t) + r_i(t) = 2R \quad (1)$$

Let: $$r(t) = [r_i(t) - r_t(t)]/2 \quad (2)$$

By performing normalization, there is: $x(t) = r(t)/R \quad (-1 \leq x(t) \leq 1)$ (3)

Namely: $$x(t) = [r_i(t) - r_t(t)]/2R \quad (4)$$

Where, $x(t)$ changes (see formula (1) to formula (4)) reflect the changes in the proportion of technological innovation and institutional innovation. When technological innovation is dominant: $x(t) < 0$, when institutional innovation is dominant: $x(t) > 0$, when technological innovation and institutional innovation are dominant collaboratively : $x(t) = 0$.

The co-evolution process of technological innovation and institutional innovation is affected by the urban development environment, including resource reserves, national resource policy guidance, urban economic status, urban industrial development strategies, etc., which make the city' s innovation preferences constantly change[3]. For instance, if technological innovation is preferred, the proportion of technological innovation input will increase, and vice versa. Here, the probability distribution is used to describe the evolution equation of industrial development and innovation preference of resource-based cities. See formula (5), formula (6).

Forest Chemicals Review
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The probability of innovation input at t time (r_t, r_i) is expressed as:

$$P(r_t, r_i; t) = P(r, t) \tag{5}$$

It meets the normalization condition: $\sum_{r=-R}^{R} P(r,t) = 1$ (6)

The change in the proportion of input in technological innovation and institutional innovation is as follows:

$$P_t \to t(r_t, r_i) = p\downarrow(r) \qquad P_i \leftarrow t(r_t, r_i) = p\uparrow(r) \tag{7}$$

Formula (7) can express the transition probability of a single resource input per unit time, and the transition probability of all resources can be expressed as in formula (8):

$$K\downarrow(r) = r_t p\downarrow(r) = (R-r)p\downarrow(r) \quad K\uparrow(r) = r_i p\uparrow(r) = (R-r)p\uparrow(r) \tag{8}$$

Then the motion equation of $P(r,t)$ can be expressed as:

$$dP(r,t)/dt = [K\uparrow(r-1)P(r-1,t) + K\downarrow(r+1)P(r+1,t)]$$

$$-[K\uparrow(r)P(r,t) + K\downarrow(r)P(r,t)] \tag{9}$$

The right end of formula (9) represents the probability flow of mutual transformation between elements in a unit time, and a unit of resources is changed each time. According to the definition of probability, the average value $\langle r \rangle$ satisfies formula (10) under certain approximate conditions:

$$d\langle r\rangle/dt = \sum_{r=-R}^{R} r dP(r,t)/dt = \sum_{r=-R}^{R} [K\uparrow(r) - K\downarrow(r)] \cdot P(r,t)$$

$$= K\uparrow(\langle r\rangle) - K\downarrow(\langle r\rangle) \tag{10}$$

The motion equation of the average value $\langle r \rangle$ is transformed into the equation of the average value $\langle x \rangle$: $d\langle x\rangle/dt = A(\langle x\rangle)$. Here, we define the driving force as shown in formula (11):

$$A(\langle x\rangle) = (1/R)K\uparrow(\langle r\rangle) - K\downarrow(\langle r\rangle)$$

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$$= (1-\langle x\rangle)P\uparrow(R\langle x\rangle) - (1+\langle x\rangle)P\downarrow(R\langle x\rangle) \qquad (11)$$

The equation can be simplified to formula (12): $dx(t)/dt = A(X(t))$ (12)

2.2 The distribution parameters of technological innovation and institutional innovation

It can be seen from equation (11) that the driving force of innovation depends on both the resource input $x(t)$ at time t and also the transfer probability $P\uparrow(x)$ of single resource at time t. $P\downarrow(x)$, the transfer probability is determined by the input preferences of technological innovation and institutional innovation, that is, the mutual change factor α, and the transfer intensity between resources, namely the coordination factor β. The driving force A can also be written as a function of the parameter α, β as shown in formula (13):

$$A(x;\alpha,\beta) = (1-x)P\uparrow(x;\alpha,\beta) - (1+x)P\downarrow(x;\alpha,\beta) \qquad (13)$$

Where: $P\uparrow(x;\alpha,\beta) = \nu_{exp}(\alpha+\beta x)$ $P\downarrow(x;\alpha,\beta) = \nu_{exp}(-(\alpha+\beta x))$ (14)

ν is the scale factor of A, and the value is different due to the different unit selection.

It can be seen from equation (14) that the contribution of $\alpha > 0$ to $P\uparrow$ is greater than 1, and the contribution to $P\downarrow$ is greater than 1. At this time, the amount of resource input for institutional innovation increases. On the contrary, when $\alpha < 0$, the amount of resource input for technological innovation increases. Under a big value β, if $x > 0$, the amount of resource input for institutional innovation will increase, and if $x < 0$, the amount of resource input for technological innovation will increase.

In order to better analyze the interactive evolution of technological innovation and institutional innovation, the driving force A is regarded as the negative degree of a certain potential function $V(x;\alpha,\beta)$, as shown in formula (15):

$$A(x;\alpha,\beta) = -\partial V(x;\alpha,\beta)/\partial x \qquad (15)$$

Suppose: $V = (2\nu/\beta^2)[\beta x\sinh(\alpha+\beta x) - (1+\beta)\cosh(\alpha+\beta x)]$ (16)

The analysis of formula (16) shows that α is an interconversion factor, and its change is as follows:

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when $x<0$, the resource input in technological innovation exceeds the resource input in institutional innovation, and $\alpha(t)$ should tend towards institutional innovation,. $\alpha(t)\xrightarrow[t\to\infty]{}\alpha_0$.On the contrary, when $x>0$, the resource input in institutional innovation exceeds the resource input in technological innovation, $\alpha(t)$ should tend to technological innovation, $\alpha(t)\xrightarrow[t\to\infty]{}\alpha_0$ and the equation of the interconversion factor $\alpha(t)$ can be written, as shown in formula (17):

$$d\alpha(t)/dt=\omega[\alpha_0-\alpha(0)]\exp[-\lambda x(t)]-\omega[\alpha_0+\alpha(0)]\exp[\lambda x(t)] \quad (17)$$

α_0 is the extent of resource input, that is, the range of the interconversion factor α, λ is the speed parameter that changes with x, and ω is the flexibility of industry development innovation preference. The change of innovation preference has a positive effect on the co-evolution of innovation, as shown by the dotted line in Figure 1.

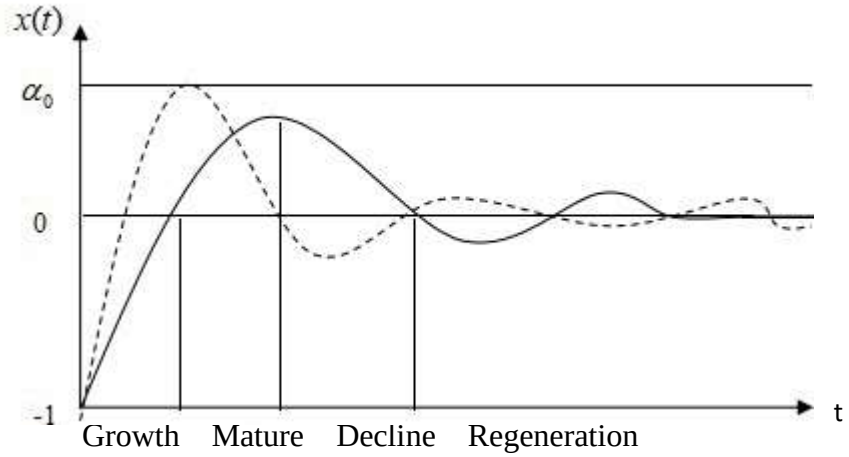

Figure 1:The dynamic evolution process of the industrial development in resource-based cities

Through the analysis of the co-evolution model of institutional innovation and technological innovation, it can be seen that in the industrial development process of resource-based cities, the synergistic interaction of institutional innovation and technological innovation should be maintained, so that it will evolve to a harmonious and stable state dominant by the two in the regeneration period. That is, $x(t)=0$. In the growth period of resource-based city development, innovation in resource technology is required to provide better products and services, and accumulate wealth for urban development. It can be set to $x(0)=-1$. After the corresponding parameters are set according to each development stage, it can be substituted into the above equation to obtain the innovation co-evolution diagram of industrial development in resource-based cities, as shown in Figure 1. $x(t)$ represents the change of innovation

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preference. In the growth stage of resource-based city development, $x<0$, innovation collaboration is manifested as technological innovation dominance. In the mature and decline periods of resource-based city development, $x>0$, innovation coordination is manifested as institutional innovation dominance. In the regeneration period of resource-based city development, $x\to 0$, innovation synergy is manifested as the co-dominance of technological innovation and institutional innovation.

The process of formation and upgrading of the industrial advantages of resource-based cities is also the process of industrial innovation. The evolution of industrial advantages is driven by technological innovation and institutional innovation, which in turn enables industrial form innovation, industrial structure innovation, industrial organization innovation, and industrial regional innovation.

III.THE HYPERCYCLE STRUCTURE OF INDUSTRIAL EVOLUTION IN RESOURCE-BASED CITIES

The hypercycle theory is an important component of the self-organization theory. The theory points out that "cycle" is a universal connection concept of things, which is divided into reaction cycle, catalytic cycle and hypercycle. The hypercycle system forms a self-organization mechanism through the interaction between the respective replication units in the system, and pushes the evolution of the system to a higher level of orderly state. The hypercycle theory can be applied to industrial development of resource-based cities to explain the evolution process of industrial advantages.

The evolution of the industrial advantages of resource-based cities is inseparable from catalytic effects. These catalysts derive from the external imposition of the system and the autonomous formation within the system, such as institutional innovation from the system environment (finance incentives and support policies, etc.), and technological innovations (new technologies, new processes, new knowledge, etc.) induced by interests and competition within the system. Due to the existence of these catalysts, a hypercycle structure is formed in the evolution of industrial advantages.

TABLE 1. Comparison of the evolution of industrial advantages and biological evolution

Biological evolution system	Industrial competitive advantage evolution system
Self-replication unit($I_1, I_2, ...I_n$)	Enterprise (Enterprise 1, Enterprise 2, ..., Enterprise n)
Catalyst or replicase($E_1, E_2, ...E_n$)	Technological Innovation and Institutional Innovation Synergy System
Replication process of the self-replication unit	Multiple companies interact and develop to form an industry
Replicase is conducive to the replication of self-replication units	the industry's competitive advantage increases

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Replicase is not conducive to the replication of self-replication units	the industry's competitive advantage disappears
mutation of the self-replication unit	drives the formation of a new stable hypercycle, and increases the industry's competitive advantage

If the evolution of the industrial advantages of resource-based cities is regarded as a hypercycle system, the basic unit enterprise in the industrial system can be regarded as each self-replication unit, that is, each reaction cycle unit, and the synergy innovation system of technological innovation and institutional innovation can be regarded as replicase, that is, catalysts. These replicases not only drive the development and evolution of the enterprise itself, but also affect the development of other enterprises. Moreover, it establishes an interactive and collaborative coupling relationship between enterprises, which in turn affects the entire industrial system, drives the evolution of industrial competitive advantages, and the evolution of resource-based cities' industrial competitive advantages. The comparison with the evolution of traditional biological evolution systems can be described in Table 1. The evolution process of resource-based cities' industrial competitive advantages is essentially a process of achieving industrial innovation driven by technological innovation and institutional innovation under industrial reaction cycles, catalytic cycles, and hypercycles. The way is to improve the competitiveness of enterprises through innovation, and then improve the evolution of the overall competitiveness of the industry.

Ⅳ.INNOVATIVE MODEL OF INDUSTRIAL DEVELOPMENT IN RESOURCE-BASED CITIES

There are reaction cycles, catalytic cycles, and hypercycles between resource-based industries and non-resource industries, the external environment, and regional economies. Through such a hypercycle structure, industries, industrial chains, industrial clusters, and resource-based urban agglomerations all undergo respective self-replication and catalysis, so that industrial system of resource-based cities evolve to a new orderly state.

4.1 Industrial form innovation model

Industrial form innovation is the process of forming industrial advantages based on product upgrades, new technology applications, and market concentration, which takes the enterprise as the core and innovation as the driving force. The industrial form innovation of resource-based cities is a reaction cycle process within the industrial system (as shown in Figure 2). The development and evolution of resource-based industries and emerging alternative industries all follow the reaction cycle process, which take the industrial system composed of similar enterprises as a self-replication unit (I) in the reaction cycle, and technological innovation and institutional innovation activities as catalysts in the reaction cycle (E1). Through the reaction cycle, new technologies, new processes and new markets (E2) are generated, thereby improving market competitiveness of the industrial system. This process is also the process of formation of

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Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

industrial competitive advantage.

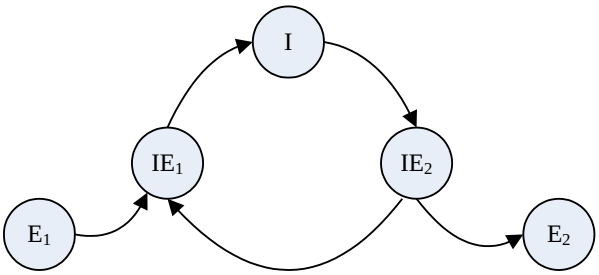

Figure 2: Industrial Form Innovation Map

Resource-based industries, as the traditional leading industries of resource-based cities, demonstrate obvious comparative advantages. However, it is precisely because of the abundance of resources and the pursuit of high yield in resources that the development of resource-based industries is mostly extensive[4]. Regarding resource-based industry form innovation, on the one hand, we must improve the level of technology and equipment through technological innovation, etc. In view of the scarcity of resources, we need develop and introduce high-efficiency, low-consumption, and emission-reducing new technologies and new processes to improve resource utilization rate. On the other hand, through enterprise management innovation and government system innovation, large-scale enterprises' cross-regional mergers, acquisitions and reorganizations are needed.

Emerging alternative industries are the new pillar industries of resource-based cities. Relying on the capital accumulation provided by resource-based industries, cities take technological innovation and institutional innovation as the main driving forces to attract foreign capital and technology, contribute to the growth of industries with great market potential, outstanding growth potential and obvious competitive advantages through industrial transfer, incubation and cultivation. The emerging alternatives are mostly based on knowledge innovation and have higher industrial technology content. From a long-term development perspective, it is easier to form industrial advantages in the market, which is an important way for resource-based cities to enhance the industrial competitiveness[5-7].

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4.2 Industrial structure innovation model

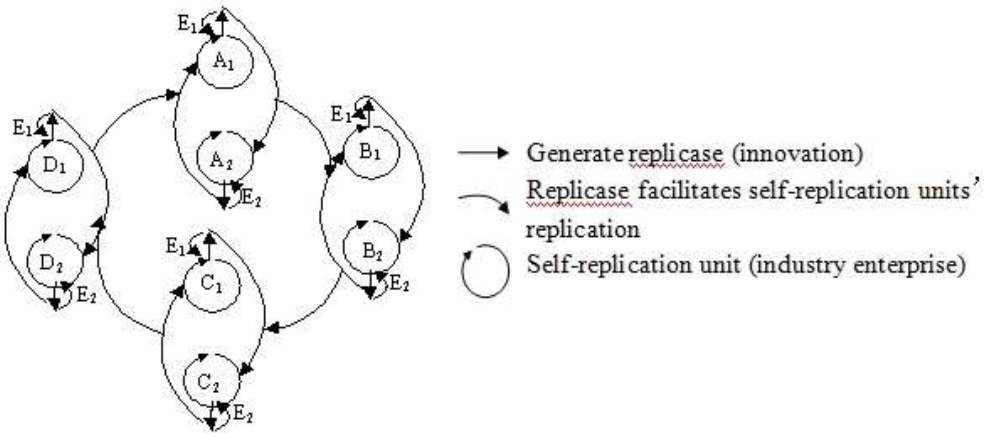

Figure 3: Industrial structure innovation map

The industrial structure innovation of resource-based cities is a hypercycle process of mutual promotion and integration of various industries in the industrial chain (as shown in Figure 3). The industries in resource-based cities are regarded as a dual supercycle structure. The replicase produced by the enterprises in the industry has a positive role in promoting both itself and the other party. That is, the incentive system of industrial development and technological innovation among peers will make enterprises develop steadily, promote each other, and form a dual hypercycle organization. At the same time, the industrial hypercycle organization and upstream and downstream industries undergo catalyzation through replicase, so that two or more separate industries can form a new stable industrial chain in the process of partial or complete integration, thereby promoting industrial development and industrial structure optimization, shaping a more competitive industrial structure. This process is also a process of enhancement of industrial competitiveness.

The development of industry chain in resource-based cities should focus on the extension of the vertical industry chain and the broadening of the horizontal industry breadth. The extension of the vertical industrial chain means the vertical integration of the upstream and downstream products of the industry. The industrial structure of resource-based areas is generally dominated by resource industry, with a relatively simple structure, a short industrial chain, and low high-tech content and high added value of products, so it is necessary to integrate the scientific and technological resources of upstream and downstream enterprises. In view of the common technical problems in the industrial development, there is need to integrate the innovation activities on the chain, extend forward to the basic links of industrial development and technological research and development link, guide innovation entities to tackle technological problems in the industrial development, expand the in-depth product development and market sales links backward, rely on core large enterprises to promote the merger and integration of enterprises in the industrial chain, thus enabling transition from extensive mining and resource preliminary

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processing to resource-protected intensive processing. The broadening of the horizontal industry breadth is to integrate industries with a small degree of industrial relevance and having no direct input-output relationship. The resource dependence of resource-based cities must be transformed by cultivating new alternative industries, thus actively pushing large-scale core enterprises to carry out diversified operations. While improving economic efficiency and expanding economic scale to achieve the horizontal integration and development of industries, there is need to promote the mutual penetration of different industries and the same industry. High-tech can penetrate into traditional industries to improve industrial efficiency, promote economic structural upgrades, and generate new industries. The horizontal and vertical development of the industrial chain can effectively enhance the industrial capacity of the chain and support the optimization and upgrading of the industrial structure.

4.3 Innovative model of industrial organization

The industrial organization innovation of resource-based cities is a hypercycle process of interaction between industries and supporting institutions in the industrial cluster (as shown in Figure 4). First, each industry in the cluster meets the dual hypercycle condition, and the knowledge sharing and spillover within the cluster, as well as the institutional innovation tilt are the replicase. The replicase is beneficial to its own industry, which also actively promotes the upstream and downstream industries of the industrial chain. At the same time, there are also research institutes, intermediary institutions and other industry-related supporting institutions in the cluster. These institutions themselves play the role of catalysts, having functions such as knowledge creation and transmission, and providing innovative services for the industry. The development of clusters is also dynamically evolving. Due to the cooperation and competition in the market, clusters will be continuously strengthened with the catalytic process, which in turn drives the development of the industrial system and forms a more stable industrial advantage. This process is also a process of deepening of the industrial advantage.

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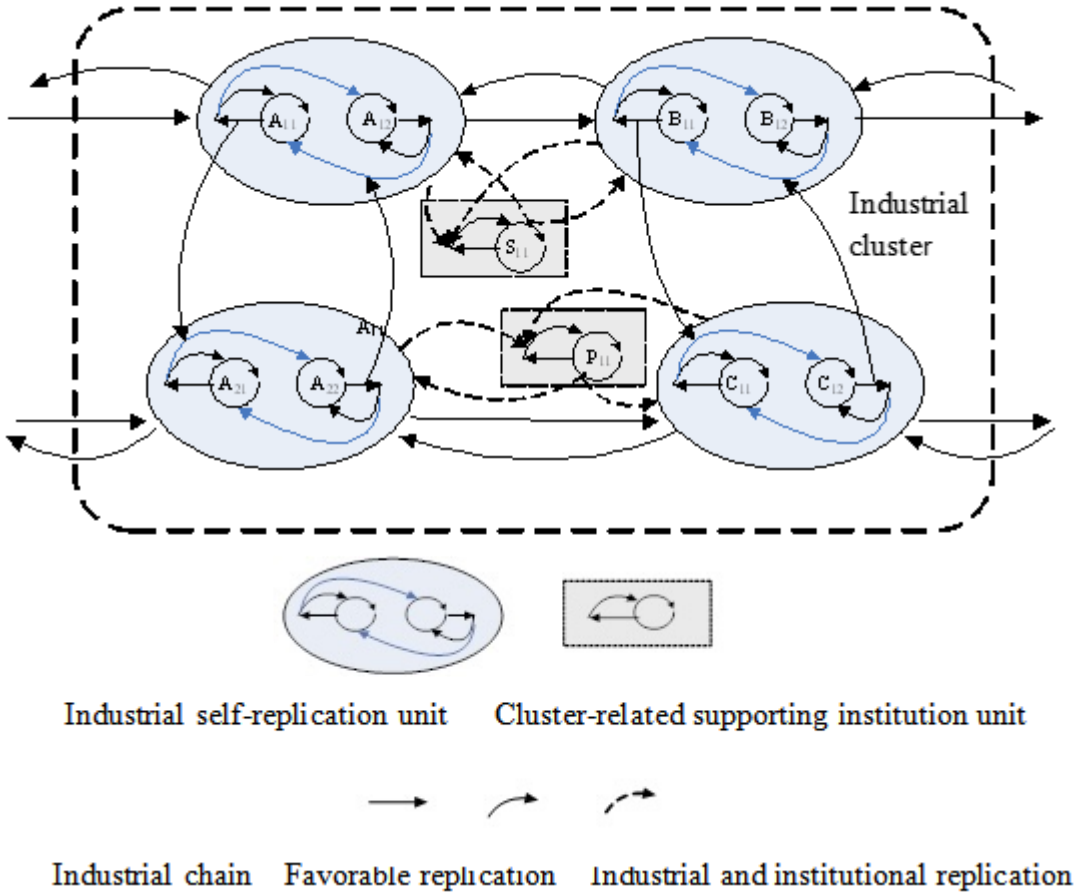

Figure 4: Industrial Organization Innovation Map

Industrial clusters change the spatial layout of industries and enhance industrial advantages through agglomeration effects. Resource-based industries in resource-based cities are the predominant conditions for urban development. They are concentrated in geographical areas, so that production time is lower than the average labor time of society. This gives resource-based industries obvious advantages, so that resource-based industries easily form specialized division of labor around the core resource enterprises, gradually displaying scale effects, and forming resource-based industrial clusters, thus becoming an organizational carrier for the concentration, optimization and development of the industrial chain[8,9]. At the same time, resource-based cities' non-resource-based industry clusters are also one of the factors in the selection of urban leading industries. If industries in a certain area can form industrial clusters and produce industrial agglomeration effects, they will easily become relatively advantageous industries in the region, which are also often selected as the dominant industries.

4.4 Industrial regional innovation model

The industrial regional innovation of resource-based cities is a hypercycle process established on the correlation between the industrial chain and industrial clusters (as shown in Figure 5). The agglomeration

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of the industrial chain does not require the enterprises on the chain to converge together in space, but some nodes can be outside the cluster. That is, nodes on the industrial chain can be located in various cities in the urban agglomeration. The replicase produced by enterprises in the industry has a positive effect, which can promote the development of enterprises themselves and peers. These replicases mainly include the government's effective institutional innovation and technological innovation among enterprises, which enable the industry to form a stable dual hypercycle structure. The replicase is beneficial to its own industry, which also actively promotes other industries of the industrial chain. At the same time, related supporting institutions in the cluster also provide innovative replicase to promote industrial development. While various industries and organizations interact with each other, new industrial structures may be derived. All industrial nodes are located in various links of the industrial chain, distributed in various cities in the urban agglomeration, which provide more cooperative and competitive advantages for industrial agglomeration, and continuously play the role of catalysis to promote the improvement of industrial competitive advantages. This process is also a process of consolidation of industrial advantages.

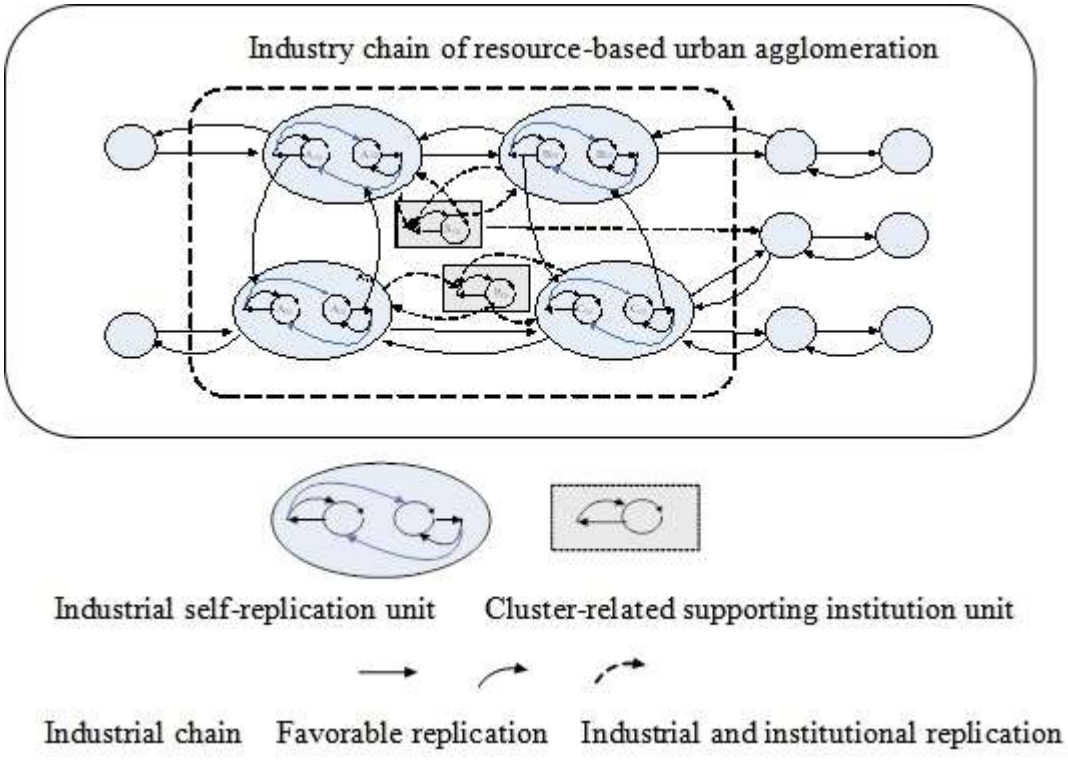

Figure 5: Industrial regional innovation map

Resource-based cities rely on their status in resource-based city clusters, make full use of the comparative advantages of industries between cities in the cluster, and rationally optimize the allocation of industrial resources, thereby effectively improving economic benefits and safeguarding the enhancement of industrial competitiveness[10-12]. Industrial chains and industrial clusters are the main forms of

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linkages between resource-based cities. Through the linkage of industrial chains, inter-city industries directly promote the joint development of various node industries and related supporting enterprises. Industries can maintain their original advantages, and under this premise, give play to the technical and economic linkage efficiency between the upstream and downstream industries to improve the added value and economic benefits of the industry. Industries in the industrial cluster can effectively exert the agglomeration effect in the cluster, strengthen professional division of labor and collaboration, reduce the industry cost in the cluster, increase the external economic benefits, stimulate innovation and emergence of new industrial branches through intra-cluster cooperation and competition. Participation in market competition in the form of clusters has stronger comparative advantages and market competitiveness.

V. CONCLUSION

The industrial development of resource-based cities is a dynamic evolution system. Due to its dependence on the resource industry, the transformation and development of cities urgently need driving factors. As a sequence parameter, the coordination of institutional innovation and technological innovation can effectively drive the evolution of industrial development, lead the adjustment of industrial structure, and give rise to the self-organization process in industrial transformation of resource-based cities. On the basis of the evolution of the industrial development power, considering the spatial structure layout from "point" to "line", to "surface", and then to "domain", combining the theory of hypercycle, we propose the process of formation, improvement, deepening and consolidation of the industrial advantages of resource-based cities, that is, the hypercycle process of industrial form innovation, industrial structure innovation, industrial organization innovation, and industrial regional innovation, thereby providing theoretical support for the research on the industrial development of resource-based cities.

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