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ARTICLE

An Analysis of the Operation Mechanism of Chemical Industry Park Ecosystem Based on Theory of Ecological Organization

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ABSTRACT

Based on the theory of ecological organization, this paper analyzes the operation mechanism of chemical industry park (CIP) ecosystem by means of dynamic simulation. The research shows that the CIP ecosystem is a complex ecological system whose operation mechanism includes two levels, namely individual enterprises and ecosystem. At the level of individual enterprise, there are competition, symbiosis, invasion and other interactions between enterprises in the CIP ecosystem. Through the pre-determined judgment of the competition effect coefficient and the symbiosis effect coefficient, we calculate how the enterprises influence each other, and then generate their respective operation paths, and finally realize the long-term balance of the system. At the level of ecosystem, the CIP ecosystem makes self-organizing and self-adaptive adjustments and changes due to the changes of the external environment in policy, manpower, technology, capital, market, etc., thus reaching the equilibrium state of coordinated operation and stable symbiosis with the external environment.

KEYWORDS

Ecosystem; operation mechanism; enterprise evolution; ecological organization; environmental protection policy

1 Introduction

With the rapid development of technology, the chemical industry has also played a vital role in other industries [1,2], while is regarded as a major threat to human health and the natural environment because of increasingly serious environmental pollution. As many countries take measures to reduce environmental damage, green themes have received increasing attention in academia and politics. China is the world's largest chemical country. The chemical industry has developed rapidly and become one of the pillar industries in China. In 2000, the Chinese government started to optimize the management of chemical enterprises by establishing CIPs. In the end of 2018, there were 676 key CIPs in China, with a total output value accounting for about 60% of the total output value of China's petroleum and chemical industry, among which 57 were national CIPs, 351 were provincial-level CIPs, and 268 were city-level CIPs [3]. Take Shandong Province, the largest province in China's chemical industry, as an example. The province plans to reach 30% by 2020 and 40% by 2022 on the basis of the existing 20% rate of chemical companies entering the park [4]. The development of CIPs has become an effective way to develop

China's chemical industry. The environmentally friendly development of chemical industry parks (CIPs) is of great importance to China.

However, the aggregation of chemical enterprises in CIPs has both advantages and risks. Firstly, geographic proximity and business strategic consensus strengthen the cooperation between enterprises [5–7] and promote innovation and overall competitiveness. Secondly, the sharing of infrastructure in CIPs can improve competitive advantages [8]. The clustering of the chemical industry provides convenience for local governments to carry out effective environmental monitoring. In terms of risks, the aggregation of chemical enterprises may increase risks and threats to the environment in the case of insufficient environmental protection, safety, and safeguard measures [9–11].

Developed countries have established CIPs for decades. Most of them have hardware advantages such as superior geographic location, convenient transportation facilities, and perfect park infrastructure, as well as strong environmental awareness, technology research and development, and market forecasts. However, emerging market countries has short period of CIP development process, and lack construction experience. Standards and regulations of CIPs are not sound. There have been many problems in industrial planning, entry barriers, safety risks, and environmental pollution for a long time. These problems also appear in CIPs as the chemical industry is accelerating the concentration of the park. Take chemical parks in China as an example, at present, most of the more advanced large-scale petrochemical park projects are mainly based on the introduction of technology, and the number of proprietary technologies with independent intellectual property rights is small. And some small chemical parks have become clusters of backward production capacity.

In nature, all individual organisms constitute the ecosystem together through interaction and evolution. Meanwhile, the ecosystem influences and interacts with the external environment, whose development and evolution can affect individual organisms. The gathering of a large number of studies, education, production, and other individual enterprises related to the chemical industry in CIPs is similar to the ecosystem in nature. Individual enterprises interact with and influence each other in CIPs which also interact with the external environment and affect the development of internal enterprises. Environmental protection, economic development and social harmony should be considered in the construction and operation of CIPs. The smooth construction and operation of CIPs requires the joint efforts of various management departments of the local government and the chemical companies in the park. Once one of them fails to perform their duties well, it may cause the collapse of the entire system.

At present, many studies have been carried out on the CIPs in China, such as energy-saving measures and potential [12], material metabolism [13] and material flow analysis, including carbon [14], sulfer [15,16] and chlorine [17,18]. However, little research systematically used the theory of ecological organization to analyze the operation mechanism of the CIP ecosystem.

This paper started with the theory of ecological organization, constructed the ecological organization system of CIPs from the aspects of individual enterprises and ecosystem, and identified variables that affect the greening of CIPs in different level system. In addition, it analyzed the operation mechanism of CIPs and conducted simulation research by taking individual enterprises with different levels of environmental protection and changes in the external environment like national environmental policies as examples. The study is helpful to understand the ecological process of the green development of CIPs, and tried to supplement the current analysis on the ecological theory of CIPs, hoping to provide a certain reference for the actual development of CIPs.

This paper was organized as follows: Section 2 introduced the construction of the CIP ecosystem; Section 3 analyzed the operation mechanism of the CIP ecosystem at the level of individual enterprises; Section 4 analyzed the operation mechanism of the CIP ecosystem at the level of ecosystem;

Section 5 summarized the main content of this paper and put forward suggestions on the environmentally friendly development of CIPs and enterprises.

2 Construction of the CIP Ecosystem

Based on the analysis framework of ecosystem "individual enterprises-CIP ecosystem-the external environment", this paper proposed the framework of the CIP ecosystem, as shown in Fig. 1. The CIP ecosystem is composed of individual enterprises that influence and interact with each other. Meanwhile, CIP as a whole interacts with the external environment, whose overall development drives and affects the development of individual enterprises within the ecosystem [19].

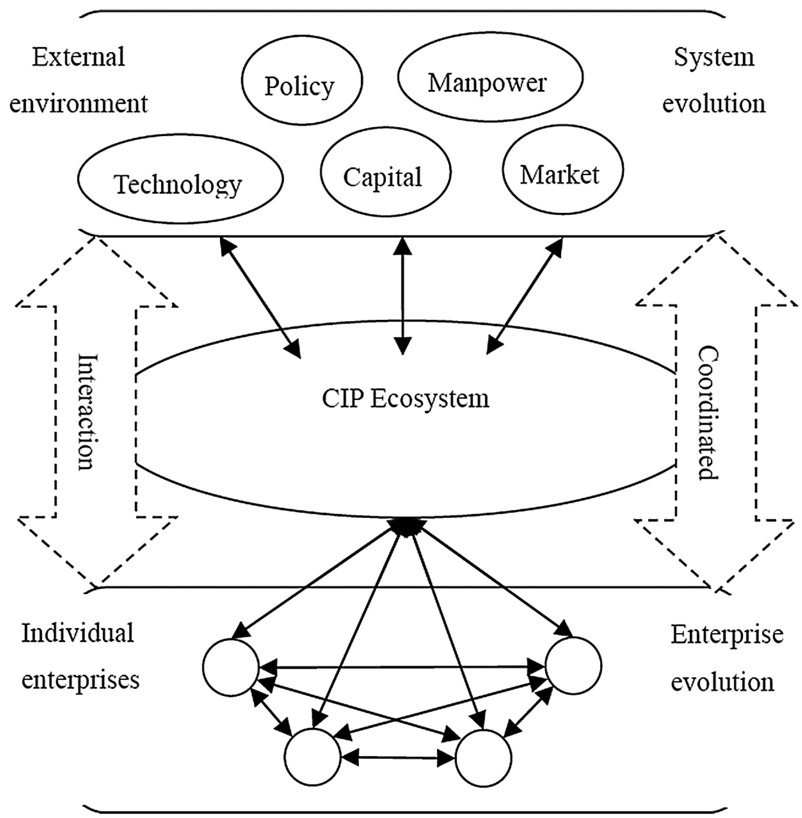

Figure 1: Schematic diagram of the CIP ecosystem

At the level of individual enterprises, this paper held that individual enterprises in CIPs have "competitive", "symbiotic", "invasive" and other mutual relations based on the theory of ecological organization. As for "competition", individual enterprises in CIPs may have a competitive relationship because of sharing public resources and facing similar development environments, like the main business belonging to the same field. With regard to "symbiosis", individual enterprises in CIPs have an obviously mutually beneficial and symbiotic relationship with upstream and downstream enterprises. They can make use of respective technological advantages, infrastructure and other resources together with complementary enterprises, thus achieving mutual promotion and development. Regarding "invasion", CIPs are like an ecosystem in which preexisting individual enterprises are influenced by the entrance of "alien species"-new-type enterprises.

From the perspective of the CIP ecosystem, it interacts with the external environment. Currently, the CIP ecosystem is affected by several external factors, including policy, manpower, technology, capital, market, etc. Individual enterprises in the CIP ecosystem interact with the external environment whose changes improve the adaptability of individual enterprises. The reaction of many individual enterprises constitutes the overall reaction of the ecosystem, which finally realizes both internal coordinated symbiosis and external adaptive development.

3 An Analysis of the Operation Mechanism of the CIP Ecosystem at the Level of Individual Enterprises

At the level of individual enterprises, this paper referred to the relevant models and methods of ecological organization theory. It also analyzed the operation mechanism of the CIP ecosystem from the perspectives of competition, symbiosis, and invasion.

3.1 Analysis of Competitive Operation Mechanism

Individual enterprises in CIPs may have a competitive relationship in production resources, product markets, and other aspects, if their business fields overlap with each other to some extent and generate competition similar to the natural system. This paper used a biological competition evolution model—the Lotka-Volterra model—as a reference to analyze the competition evolution and operation mechanism of individual enterprises in CIPs [20].

Assume two enterprises in a CIP have similar business fields and a competitive relationship in production resources and product markets [21]. The following model is established:

$$f(q_1, q_2) = dq_1/dt = r_1 q_1 (1 - q_1/K_1 - J_{12} q_2/K_1) \tag{1}$$

$$g(q_1, q_2) = dq_2/dt = r_2 q_2 (1 - q_2/K_2 - J_{21} q_1/K_2) \tag{2}$$

In which q_1 q_2 and are the actual turnovers of individual enterprises 1 and 2 in the CIP respectively; K_1 and K_2 represent the turnovers of individual enterprises 1 and 2 without a competitive relationship; r_1 and r_2 refer to the turnover growth rates of individual enterprises 1 and 2 respectively, and are assumed to be greater than 0; J_{12} is the competitive effect of individual enterprise 2 on 1 while J_{21} means the competitive effect of individual enterprise 1 on 2.

Let $f(q_1, q_2) = g(q_1, q_2) = 0$ to obtain:

$$r_1 q_1 (1 - q_1/K_1 - J_{12} q_2/K_1) = 0 \tag{3}$$

$$r_2 q_2 (1 - q_2/K_2 - J_{21} q_1/K_2) = 0 \tag{4}$$

The above equations were solved to obtain the equilibrium points of two enterprises, namely, $E_1(0, 0)$, $E_2(K_1, 0)$, $E_3(0, K_2)$ and $E_4(K_1(1 - J_{12})/(1 - J_{12}J_{21}), K_2(1 - J_{21})/(1 - J_{12}J_{21}))$ in turn.

The stability of the four equilibrium points was discussed in sequence to determine whether the state was sustainable. Assume:

$$\begin{aligned}
(\partial f/\partial q_1)_0 &= \lambda_{11} = (r_1 - 2r_1 q_1/K_1 - r_1 J_{12} q_2/K_2)_0 \\
(\partial f/\partial q_2)_0 &= \lambda_{12} = (-r_1 J_{12} q_1/K_2)_0 \\
(\partial g/\partial q_1)_0 &= \lambda_{21} = (-r_2 J_{21} q_2/K_1)_0 \\
(\partial g/\partial q_2)_0 &= \lambda_{22} = (r_2 - 2r_2 q_2/K_2 - r_2 J_{21} q_1/K_1)_0
\end{aligned} \tag{5}$$

$E_1(0,0)$ was substituted into the equation to obtain $\lambda_{11} = r_1$, $\lambda_{12} = 0$, $\lambda_{21} = 0$ and $\lambda_{22} = r_2$. Therefore, the characteristic equation of its matrix $|J - \omega I| = 0$ is:

$$\begin{vmatrix} \lambda_{11} - \omega & \lambda_{12} \\ \lambda_{21} & \lambda_{22} - \omega \end{vmatrix} = 0.$$

Numerical values were substituted to obtain

$$\begin{vmatrix} r_1 - \omega & \lambda_{12} \\ \lambda_{21} & r_2 - \omega \end{vmatrix} = 0 \tag{6}$$

Thus, $\omega_1 = r_1 > 0$ and $\omega_2 = r_2 > 0$ were obtained. Thus, $T = \omega_1 + \omega_2 > 0$. It can be seen that $E_1(0,0)$ is not stable.

The same method can be adopted to judge the stability of the other three equilibrium points. The results are shown in Tab. 1.

Table 1: Stability of competitive enterprises in CIPs

Competitive conditions	Equilibrium point	Final state	State description
$J_{12} < 1, J_{21} < 1$	E_4	$q_1 = K_1(1 - J_{12})/(1 - J_{12}J_{21})$ $q_2 = K_2(1 - J_{21})/(1 - J_{12}J_{21})$	The two enterprises compete with each other, but neither of them can completely suppress each other. Eventually, they achieve long-term symbiosis.
$J_{12} < 1, J_{21} > 1$	E_2	$q_1 = K_1$, $q_2 = 0$	Enterprise 1 has a greater competitive effect on enterprise 2. Eventually, enterprise 2 disappears while enterprise 1 exclusively owns the maximum capacity.
$J_{12} > 1, J_{21} < 1$	E_3	$q_1 = 0$, $q_2 = K_2$	Enterprise 2 has a greater competitive effect on enterprise 1. Eventually, enterprise 1 disappears while enterprise 2 exclusively owns the maximum capacity.
$J_{12} > 1, J_{21} > 1$	None	$\Delta < 0$, failure to achieve stability	Evolve into E_2 or E_3eventually with the differentiation of enterprise competitiveness.

According to the compliance of enterprises with various laws and regulations on environmental protection, China's Ministry of Environmental Protection rates the environmental protection level of enterprises as five categories, namely green (excellent), blue (good), orange (basically up to the standard), red (illegal) and black (seriously illegal). The two chemical technology enterprises whose level of environmental protection is blue are taken examples. In the case of certain crossing and overlapping in their business scopes, resources occupied, etc. and a competitive relationship between them, their operation mechanism is: Both enterprises cannot completely suppress each other when their mutual competitiveness is strong and balanced and will achieve respective equilibrium after a period of operation. They will establish a long-term symbiotic relationship in order to achieve the stability of the ecosystem. When the two enterprises have an obvious gap in competitiveness, the environmental protection chemical technology enterprise with strong competitiveness will occupy all the resources and markets of the whole ecosystem after a period of operation. While, the other will gradually disappear. When owning strong competitiveness, the two enterprises will gradually differentiate after a period of operation, one of which continues to improve its competitiveness and become dominant, while the other sees a gradual reduction in its competitiveness and tends to disappear.

3.2 Analysis of Symbiotic Operation Mechanism

Some individual enterprises in CIPs have a certain complementary relationship, such as resource, functional, and market complementation. Complementary enterprises can better cope with the external environment and make better development together through mutual cooperation and symbiosis. This paper uses a biological competition evolution model - the mutualism model - as a reference to analyze the symbiotic operation mechanism of individual enterprises in CIPs [22].

Assume a CIP has individual enterprises 1 and 2. The following model was established:

$$\mu(q_1, q_2) = dq_1/dt = r_1q_1(1 - q_1/K_1 + I_{12}q_2/K_1) \tag{7}$$

$$v(q_1, q_2) = dq_2/dt = r_2q_2(1 - q_2/K_2 + I_{21}q_1/K_2) \tag{8}$$

In the above model, q_1, q_2, r_1 and r_2 have the same meanings as above; K_1 and K_2 are the turnovers of individual enterprises 1 and 2 without a symbiotic relationship; I_{12} represents the synergistic promotion effect of individual enterprise 2 on 1 while I_{21} refers to the synergistic promotion effect of individual enterprise 1 on 2.

Similarly, the solution of $\mu(q_1, q_2) = v(q_1, q_2) = 0$ was solved to obtain four equilibrium points, namely $E_1(0, 0)$, $E_2(K_1, 0)$, $E_3(0, K_2)$ and $E_4(K_1(1+I_{12})/(1 - I_{12}I_{21}), K_2(1+I_{21})/(1 - I_{12}I_{21}))$.

The above-mentioned method was adopted to further judge the stability of each equilibrium point. The process was not expounded again. The final conclusion was reached: E_4 was the stable equilibrium point of the CIP ecosystem of symbiotic enterprises.

The two chemical technology enterprises that are upstream and downstream of each other are taken as examples. Two individual enterprises have symbiotic effects due to their obvious upstream and downstream supply chain relationship. They make better development and greater profits through the cooperation and sharing of one or more aspects, such as resources, technology, information and market. After a certain period of operation, the whole CIP ecosystem reaches a better stable state of development.

3.3 Analysis of Invasive Operation Mechanism

Individual enterprises in CIPs interact with each other and are influenced by external enterprises. This paper used a biological competition evolution model—the heterogeneous metapopulation model to analyze the operation mechanism between individual enterprises in CIPs and external enterprises [23].

Assume enterprises in CIPs have the same natural mortality m as external enterprises and the resource occupancy rate of each enterprise is $p_i|_{D=0} = q(1 - q)^{i-1}$ where q refers to the resource occupancy rate of the most competitive enterprise. In the absence of external enterprises, the growth rate of enterprises in the park is $c_i = m_i/.(1-q)^{2i-1}$. Under the condition of established resources in the park, the operation and evolution law of each enterprise was:

$$dp_i/dt = c_i p_i(1 - D - \sum_{j=1}^{i} p_j) - m_i p_i - \sum_{j=1}^{i-1} p_i c_j p_j \qquad i = 1, 2, \cdots, n \tag{9}$$

where i is the competitiveness ranking of individual enterprises; p_i represents the resource occupancy rate of enterprise i; c_i refers to the growth rate of enterprise i; m_i stands for the mortality of enterprise i; D denotes the ratio of the amount of change in original enterprise resources caused by external enterprises to the total resources.

Let $dp_i/dt = 0$ to obtain a stable state of the operation of the CIP ecosystem. The general solution was:

$$p_i^e = \begin{cases} \hat{p}_i \ \ if \ \ \hat{p}_i > 0 & \left[\hat{p}_i = 1 - D - \dfrac{m_i}{c_i} - \displaystyle\sum_{j=1}^{i} p_j^e (1 + \dfrac{c_j}{c_i})\right] \quad i = 1, 2, \cdots, n \\ 0 \ \ if \ \ \hat{p}_i \le 0 & D \ge 1 - m_i/c_i = 1 - (1-q)^{2i-1} \end{cases}$$

This paper uses simulation analysis to better illustrate the operation process of invasive chemical technology enterprise parks. Assume only two enterprises whose level of environmental protection is orange are in a CIP. The model was:

$$\begin{cases} dp_1/dt = c_1 p_1 (1 - p_1) - m p_1 \\ dp_2/dt = c_2 p_2 (1 - p_1 - p_2) - m p_2 - c_1 p_1 p_2 \end{cases} \tag{10}$$

Assume a chemical technology enterprise whose level of environmental protection is blue enters the CIP. The model was:

$$\begin{cases} dp_1/dt = c_1 p_1 (1 - p_1) - m p_1 \\ dp_2/dt = c_2 p_2 (1 - p_1 - p_2) - m p_2 - c_1 p_1 p_2 \\ dp_3/dt = c_3 p_3 (1 - p_1 - p_2 - p_3) - m p_3 - c_1 p_1 p_3 - c_2 p_2 p_3 \end{cases} \tag{11}$$

Assume two enterprises, with environmental protection level of orange in the CIP, reach a state of equilibrium through competition, cooperation and other means before the invasion of external enterprises. For the convenience of display and analysis, two enterprises were assumed to have a certain difference in scale and a stable market share of 0.4 and 0.2 respectively. Because of being at a relative disadvantage in environmental adaption, resource integration and other aspects, "invasive" enterprises were assumed to have an initial market share of 0.1.

(1) Assume $c_3 = 0.05, m_3 = 0.03/t,\ p_3 = 0.06$. The fitting results are shown in Fig. 2. After the "invasion" of new enterprises, original enterprises were affected in the aspect of public resources, market environment, etc. and saw a decline in market share to some extent. However, new enterprises with strong ability in environmental protection saw a constant decline in the market share of the whole ecosystem due to weak competitiveness and were finally swallowed up by more competitive enterprises. It can be seen that "invasive" individual enterprises cannot survive in the original CIP ecosystem if lacking strong market competitiveness.

Notes: The x-coordinate represents the times of simulation (operation time) while the y-coordinate stands for the resource occupancy rate of enterprises (enterprise scale), the same below.

(2) Assume $c_3 = 0.1, m_3 = 0.03/t,\ p_3 = 0.06$. The fitting results are shown in Fig. 3. Due to the stronger environmental protection ability and other market competitive advantages of "invasive"

enterprises, original individual enterprises were obviously affected and saw a significant decline in market share. After seizing certain public resources and market shares, “invasive” enterprises reached a stable state with original enterprises.

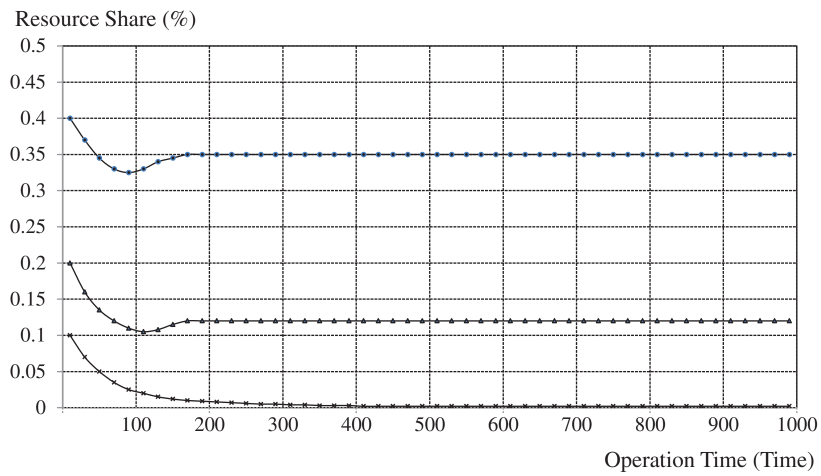

Figure 2: Schematic diagram of the operation simulation of “invasive” enterprises in CIPs (1)

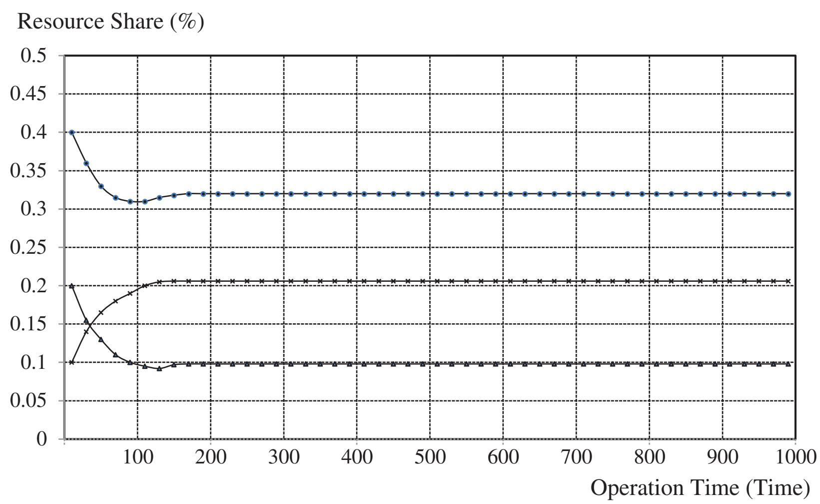

Figure 3: Schematic diagram of the operation simulation of “invasive” enterprises in CIPs (2)

(3) Assume $c_3 = 0.20, m_3 = 0.03/t,\ p_3 = 0.06$. The fitting results are shown in Fig. 4. When making major breakthroughs due to technological innovation and significant competitive advantages in environmental protection ability, “invasive” enterprises would comprehensively seize the production resources and market shares of original chemical technology enterprises, even lead to their decline and fall, and finally occupy a dominant position in the ecosystem.

As a whole, “invasive” enterprises would have a significant influence on the operation of the whole CIP ecosystem. In this paper, “invasive” enterprises were assumed to have strong environmental protection ability. However, when owning strong comprehensive competitiveness to make up for their deficiency in environmental protection, original enterprises can basically maintain original growth rates and exclude new enterprises till their extinction. When owning comparable comprehensive competitiveness with original enterprises due to their strong environmental protection ability, “Invasive” enterprises would occupy the production resources and market shares of original enterprises and finally reach a stable state of co-existence with original enterprises. In addition, when seeing a sharp rise in environmental protection ability due to technological breakthroughs and owning obviously stronger comprehensive competitiveness than original enterprises, “invasive” enterprises would lead to the shrinkage and even perishment of original enterprises and become dominant enterprises in the whole CIP ecosystem.

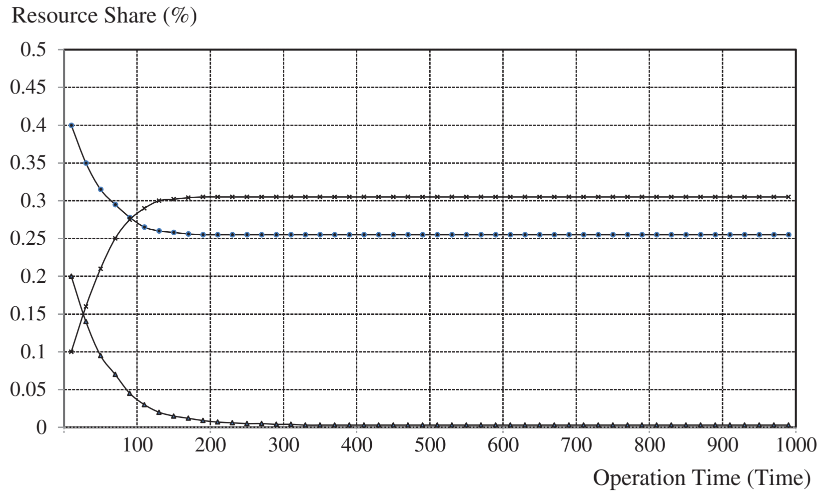

Figure 4: Schematic diagram of the operation simulation of “Invasive” enterprises in CIPs (3)

4 An Analysis of the Operation Mechanism of the CIP Ecosystem at the Level of Ecosystem

From the perspective of ecosystem, the whole CIP ecosystem as a whole interacts and operates with external policy, manpower, technology, capital, market, and many other aspects. On the basis of sorting out the external influence factors for the CIP ecosystem, this part establishes the coordinated operation evolution model of the CIP ecosystem and external environment and uses simulation analysis for simulation demonstration.

4.1 External Influence Factors for the CIP Ecosystem

This section refers to the analysis framework of the external environment in ecology and summarizes the external influence factors for the CIP ecosystem, such as policy, manpower, technology, capital, and market affecting the operation and development of enterprises in CIPs jointly [24].

First, the policy factor. As an important influence factor for the operation of CIPs, policy factor will affect the ability of the CIP ecosystem in integrating policy resources and directly influence its development direction and strategy. As for the chemical industry, thousands of chemical enterprises have been shut down and restricted in access to CIPs since the government strengthened environmental supervision in 2017. The trade war between China and the US hit the chemical industry when environmental supervision was constantly strengthened in 2018. This leads to the gradual appearance of the shutdown tide of small and medium-sized enterprises.

Second, the manpower factor. Manpower factor is of great importance for chemical technology enterprise parks. On the one hand, the gathering of high-quality talents enables chemical technology enterprises in CIPs to carry out reforms and innovations, produce more competitive new products and technologies and more efficient production modes, satisfy and even create more market demands. On the other hand, it will improve the “popularity” of CIPs, attract more talents to CIPs, carry out relevant strategic transformation and make better development with the support of stronger manpower.

Third, the technology factor. Science and technology are primary productive forces. The same is true for chemical technology enterprises. For one thing, advanced science and technology like big data and cloud manufacturing can improve the production efficiency of relevant enterprises and thus the overall production level of CIPs. For another thing, the application of science and technology can better explore the potential of human resources, which in turn can promote technological innovation and thus upgrade the CIP ecosystem on the whole.

Fourth, the capital factor. As one of the important influence factors for the operation of CIPs, capital is greatly needed by chemical technology enterprises. The financing of enterprises in CIPs is affected by national environmental policies. Capital factor is one advantage of CIPs with the financial support or policy inclination of the government. In addition, relatively loose loan policies are more conducive to raising funds due to the requirements of banks and other financial institutions for risk control. However, small and medium-sized enterprises still have great difficulties in financing at present, which is a common problem.

Fifth, the market factor. For CIPs, market test is the only standard of survival and development. Chemical technology enterprises also need to bear cost pressure with the rapid rise of upstream chemical raw material prices from 2017. In addition, the high technical barriers of some products lead to a few production enterprises. Monopoly causes excessively high price, syndicated price increase and other problems.

4.2 Operation Evolution Model of the CIP Ecosystem and External Environment

The CIP ecosystem is characterized by openness, complexity, etc., where individual enterprises interact with and influence the external environment. With self-organization ability and active adaptability, individual enterprises in CIPs can make targeted adjustments and changes according to the external environment to change their adaptability and promote the evolution of ecosystem. From the perspective of the CIP ecosystem, the ecosystem and external environment effectively interact with each other through the transfer and influence of information, materials, energy, and other elements to improve the external environment and develop the ecosystem itself. Based on the theory of ecological organization, this paper constructed the operation evolution model of the CIP ecosystem and external environment, as shown in Fig. 5.

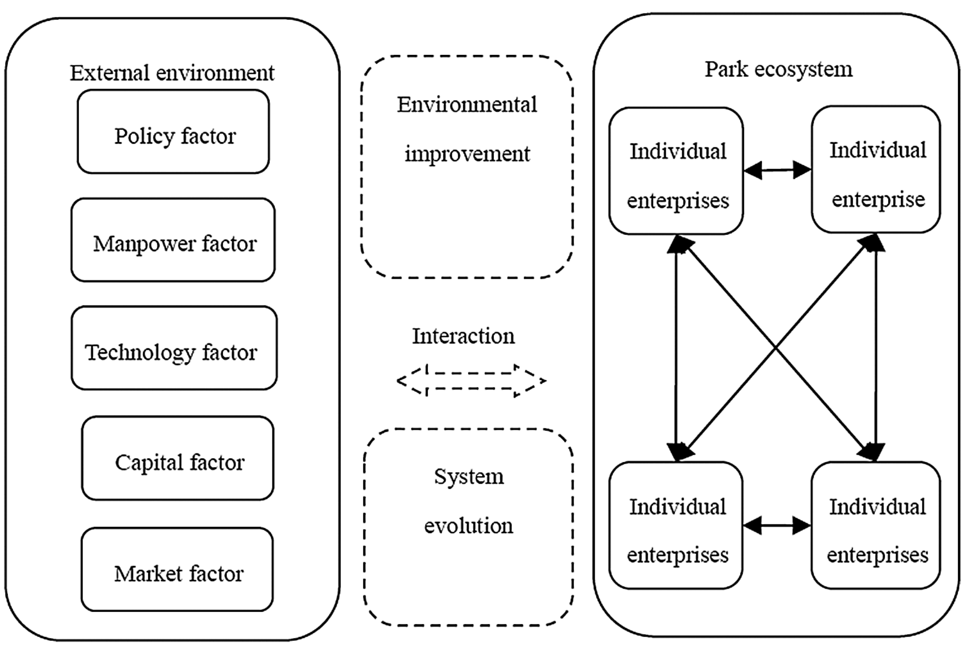

Figure 5: Operation evolution of the CIP ecosystem and external environment

Influenced by the changes in the external environment, individual enterprises in the CIP ecosystem will see constant changes, which leads to the development and solution of the ecosystem. After evolution, the CIP ecosystem will also interact with the external environment and give certain feedback to the external environment. This gives rise to the changes of the external environment in the direction conducive to the evolution of the ecosystem and improves the external environment to some degree. Finally, the CIP ecosystem realizes the development and evolution of its internal enterprises and overall evolution through interacting with the external environment and making development. It also influences the changing trend of the external environment and enables the external environment to "improve" in the direction beneficial to the ecosystem and achieve co-evolution and common development with the ecosystem. In the model, individual enterprises and the CIP ecosystem mutually influence and effectively interact with the external environment, thus finally realizing co-evolution and common development instead of completely passively accepting the changes of the external environment or actively choosing the external environment.

4.3 Simulation Analysis of the Operation of the CIP Ecosystem and External Environment

In order to intuitively present the influence of the external environment on the CIP ecosystem, a biological competition evolution model the heterogeneous metapopulation model was still used for simulation analysis. Its basic equation is consistent with the above Eq. (9). The meanings of specific indicators were not explained again. Different from the above analysis, the operation process of individual enterprises in the ecosystem under changing external environment was simulated, through changing the proportion of individual enterprises in the total resources of the CIP ecosystem and its relationship with the resource occupancy rate of the strongest individual enterprises in CIPs. Namely, whether the changes of the external environment are beneficial to individual enterprises depends on the ratio (D) of the amount of change in the resources of individual enterprises. That was caused by the changes of the external environment to the total resources and the relationship between the resource occupancy rate (p_i) of each individual enterprise.

Assume CIPs have two individual enterprises, and p_1 and p_2 to refer to the resource occupancy rates of large and small-scale enterprises respectively. The impact of the external environment on the ecosystem was simulated respectively by arranging D and p_i in order of size, as shown in Tab. 2.

Table 2: Classification for the influence of the external environment on the operation of individual enterprises

Serial No.	Condition	Influence on individual enterprises ($p_1 > p_2$)	
		Individual enterprise p_1	Individual enterprise p_2
1	$D > p_1 > p_2$	Negative	Negative
2	$p_1 = D > p_2$	Neutral	Negative
3	$p_1 > D > p_2$	Positive	Negative
4	$p_1 > p_2 = D$	Positive	Neutral
5	$p_1 > p_2 > D$	Positive	Positive

The environmental protection policies implemented in China were taken as examples for the simulation analysis of the whole ecosystem. Assume differences exist between the requirements of environmental protection policies and the environmental protection levels of previous enterprises in CIPs and lead to the difference in the size arrangement of D and p_i. The specific classification was shown below. $D > p_1 > p_2$ would be satisfied if the requirements of environmental protection policies introduced by the government were obviously higher than the environmental protection level of enterprises in CIPs. Namely, under the condition of the extremely deteriorated external environment, the reduction amount of resources in CIPs was higher than the resource occupancy of enterprises with strong competitiveness, which had an obviously negative influence on two individual enterprises whose operation simulation is shown in Fig. 6. It can be seen that the serious "deterioration" of the external environment like government policies would significantly reduce the survival and development resources of enterprises in the CIP ecosystem, seriously affect the survival and development of enterprises, and lead to a decline in the resource occupancy rate of enterprises and the constant shrinkage and even perishment of enterprises.

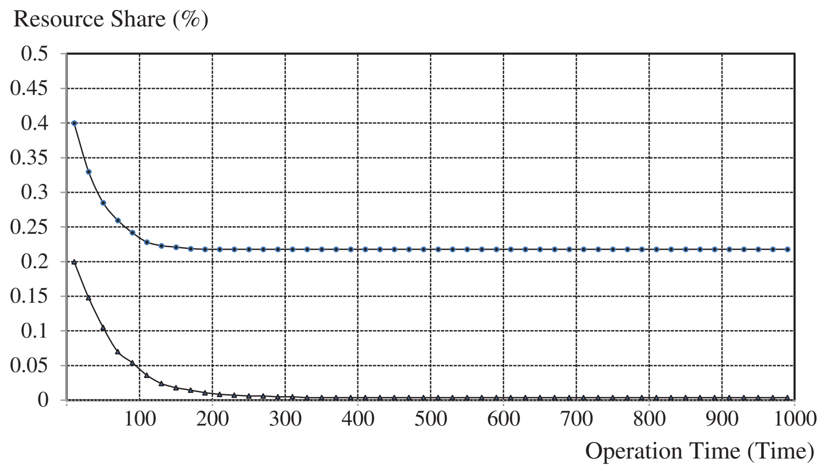

Figure 6: Simulation results of the operation evolution of the external environment and multiple individual enterprises (1)

$p_1 = D > p_2$ would be satisfied if the requirements of environmental protection policies introduced by the government were just consistent with the environmental protection level of enterprises with strong competitiveness, namely one enterprise can meet national requirements and enjoy relevant resources while the other failed to meet national requirements and was restricted. Due to the higher requirements of external environmental protection policies, the reduction amount of the overall resources of enterprises in CIPs was comparable to the resource occupancy of enterprises with strong competitiveness, which had different degrees of influence on two individual enterprises whose operation simulation is shown in Fig. 7. It can be seen that the "bad" results caused by the changes of national environmental protection policies were equivalent to the bearing capacity of enterprises with strong competitiveness, which thus had little effect on their resource occupancy rate and scale. However, the reduction of resources resulting from environmental "deterioration" was transferred to less competitive chemical technology enterprises, decreasing their resource occupancy rate and scale to some extent.

$p_1 > D > p_2$ would be satisfied if the requirements of environmental protection policies introduced by the government were in the middle of the environmental protection level of enterprises, namely one enterprise can meet national requirements and enjoy relevant resources, while the other failed to meet national requirements and was restricted. Due to the higher requirements of external environmental protection policies, the reduction amount of resources was lower than the resource occupancy of enterprises with strong competitiveness and higher than the resource occupancy of enterprises with weak competitiveness. The operation simulation of the ecosystem was shown in Fig. 8. It can be seen that enterprises with strong competitiveness can make full use of the favorable conditions of national policies, give play to their competitive advantages, seize more resources, and achieve further expansion and development, while enterprises with relatively weak competitiveness would bear the pressure of the "deterioration" of the external environment and competition from other enterprises and tend to see a decline in scale.

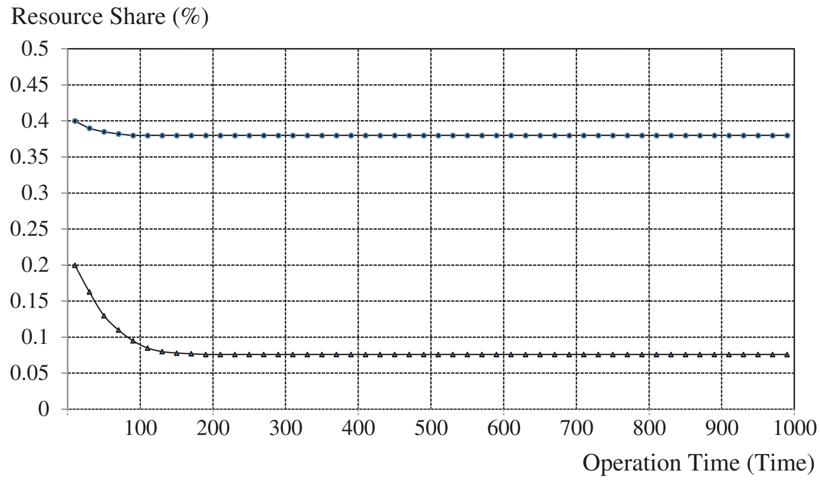

Figure 7: Simulation results of the operation evolution of the external environment and multiple individual enterprises (2)

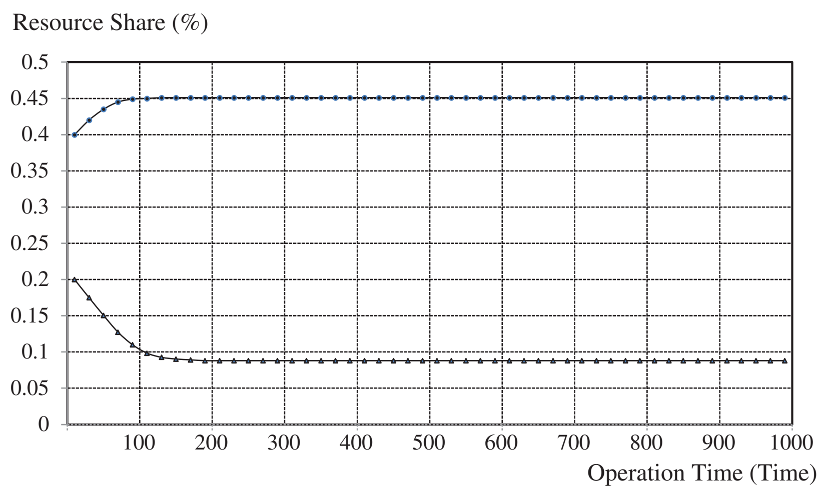

Figure 8: Simulation results of the operation evolution of the external environment and multiple individual enterprises (3)

$p_1 > p_2 = D$ would be satisfied if the requirements of environmental protection policies introduced by the government were just consistent with the environmental protection level of enterprises with weak competitiveness, namely one enterprise can just meet national requirements and enjoy relevant resources, while the other can make full use of national preferential policies. Due to the higher requirements of external environmental protection policies, the reduction amount of resources was equivalent to the resource occupancy of enterprises with weak competitiveness. The operation evolution of the ecosystem is shown in Fig. 9. It can be seen that enterprises with strong competitiveness can take advantage of the favorable resources brought by the changing external environment to gain more support in the market and further increase their scale, while enterprises with weak competitiveness can basically resist the "negative" influence of the external environment but would see a small incline in scale due to the competition of other enterprises.

The two enterprises can make full use of national preferential policies if their environmental protection levels meet the requirements of environmental protection policies introduced by the government. Namely, $p_1 > p_2 > D$ was satisfied. Due to the higher requirements of external environmental protection policies, the reduction amount of resources was lower than the resource occupancy of enterprises with weak competitiveness. Both enterprises can enjoy the dividends of national environmental protection policies. The operation simulation of the ecosystem is shown in Fig. 10. It can be seen that all individual enterprises can benefit and increase their resource occupancy rate and scale when external policies are obviously favorable to enterprises in CIPs.

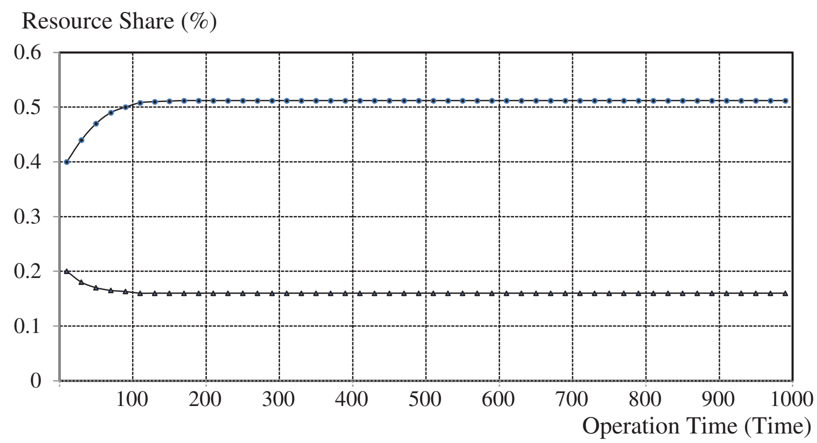

Figure 9: Simulation results of the operation evolution of the external environment and multiple individual enterprises (4)

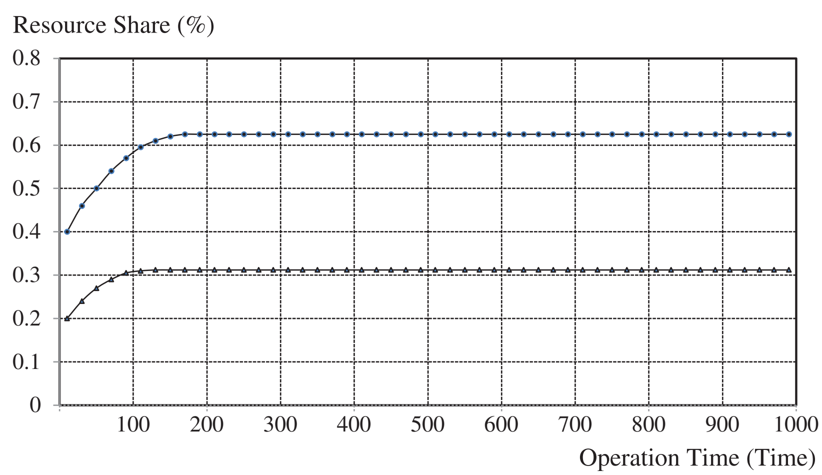

Figure 10: Simulation results of the operation evolution of the external environment and multiple individual enterprises (5)

5 Discussion and Implication

CIPs are a typical ecosystem, whose internal structure and external environment have obvious ecosystem properties. Through analysis, it is found that individual enterprises in the CIP ecosystem have competitive, symbiotic, invasive and other relations with each other. Enterprises with different levels of environmental protection were taken as examples for simulation analysis. Individual enterprises will generate respective operation paths in order to achieve long-term equilibrium within the ecosystem. For enterprises with a competitive effect coefficient less than 1, that is, enterprises with weaker competitiveness, they are often squeezed by "invading" enterprises in market share. They will be declining, or even extinct. For enterprises with a competitive effect coefficient greater than 1, that is, enterprises with stronger competitiveness, they will share the market with the "invading" enterprises in a balanced way. For the competitive effect coefficient far greater than 1, that is, extremely competitive enterprises, they will squeeze out "invading" enterprises to protect their market share. For enterprises with a symbiotic effect coefficient greater than 1, that is, enterprises with symbiotic relationship, they will co-exist and develop together. Enterprises with external invasions are similar to enterprises with competitive corporate relationships. The long-term equilibrium state depends on the competitive relationship between the invading company and the original company.

Due to changes in the external environment of the park ecosystem such as policies, manpower, technology, capital, and markets, the enterprises within the ecosystem will also perform self-organization and self-adaptation functions, resulting in corresponding adjustments and changes. Taking government environmental protection policy changes as an example, we analyzed the impact of different changes in the external environment on the enterprises in the park, and performed simulation analyses respectively to clarify the final state achieved by the coordinated operation and stable symbiosis of the park ecosystem and the external environment. If the external environment becomes better, all the enterprises in the park will get more development. If the external environment becomes worse, the competitive enterprises in the park will be less affected. But the less competitive companies will shrink significantly. If the external environment becomes extremely harsh, the entire park enterprises may shrink or even perish.

Based on the theory of ecological organization, this paper analyzed the operation mechanism of CIP ecosystem by means of dynamic simulation, and identified variables that affect the greening of CIPs in different level system. The study is helpful to understand the ecological process of the green development of CIPs, and provides a theoretical basis for the ecological evaluation of CIP and the evaluation of CIP policies.

Compared with the natural agglomeration of European and American chemical parks, the guiding role of China's central and local governments is particularly significant. The greening of the chemical park is a process of green transformation and upgrading of the CIPs under the guidance of the concept of sustainable development. This research put forward the following suggestions for China's administrative departments related to the chemical industry. First, by raising the threshold for entering the park, priority will be given to projects with green innovative technologies. At the same time, speed up the construction of green innovation carriers in the park, establish a platform for industry-university-research cooperation and several industrial innovation centers, and accelerate the improvement of the industry's independent innovation capabilities. Second, increasing fiscal and financial support and making use of existing special fund channels and science and technology plans, which are funded by the central government (special projects, funds, etc.) to provide more support for the environmental technological transformation of the chemical industry, the development of high-end products, green and safe production, the construction of public service platforms and technical research and development. At last, strengthening supervision, inspection and management, and ordering enterprises without conforming to safe and environmentally friendly production conditions to stop production for consolidation, shut down and exit the market according to law. In addition, the following suggestions are made on the environmental protection work of chemical enterprises: taking the initiative to upgrade technology and shut down outdated production facilities; carrying out strict environmental protection and improving rules and regulations; and participating in formulating national environmental policies, regulations, and standards.

Although some preliminary conclusions have been obtained from the ecological organization theory analysis and dynamic simulation results, they have not been empirically tested. In future research, it is recommended to introduce more quantitative research, using real cases and data as samples, and make further systematic analysis and causal judgment. In addition, our research background is focused on China's chemical parks, which limits its promotion on a global scale.

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