A Novel Modelling Study on Innovation Co-Evolution Mechanisms of Automobile Industrial Clusters

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***Abstract* —The aggregated behaviour of technology innovation in automobile enterprises has similar characteristics to biotic population. Based on industrial ecology and biological co-evolution, this paper proposes an innovation ecosystem for automobile industrial clusters. With the logistic equation describing the growth law of biotic population, the mathematical models of innovation co-evolution mechanisms are formulated, solved and analysed under 3 relationships: i) non-predation competition, ii) commensalism (where one benefits and the other derives neither benefit nor harm), and iii) original collaboration. These 3 models are applied to describe the enterprises' relationships in the innovation system of automobile industrial clusters. With the analysis results, this paper proposes some thoughts and suggestions on building and developing innovation ecosystems for these clusters.**

Keywords- co-evolution; automobile industrial cluster; innovation ecosystem; innovation mechanism

I. INTRODUCTION

A. Theory of industrial ecology

In the late 1960s, the American economist, Kenneth Boulding, firstly came up with the concept of ecological economics. After the 1980s, industrial ecology became a new discipline gradually, and the concept of industrial ecosystem was put forward clearly (Frosch & Gallopoulos, 1989). Industrial ecology owns the attributes of natural science and social science, it originates from the circulation of materials and the layer recursive utilization of energy in natural science. However, industrial ecology does not only solve the environmental problem. It settles the resource scarcity problem or the issue concerning with economic efficiency of resources. It is mainly about the correct disposal and effective utilization of resources and wastes. Moreover, it gets inspiration from the operational mechanism of natural ecosystem to do economical and effective adjustment to the input and output of the human industrial system [1]. In industrial Ecosystem, even though the various enterprises and organizations are independent, they form a net through some direct or indirect connections (Harvey &Randles, 2002), and this net becomes a clear compounded cluster or enterprise "ecology" [2]. Industrial ecosystem researches the interaction of different parts in the system deeply. It emphasizes on integral analysis and opposes isolated research perspective. As a consequence, the idea of integrity and systematization become the core of industrial ecosystem [3].

There are two main aspects of industrial ecology research. The first aspect is fundamental research with industrial ecology concept, research scope, and development path as major content [4-5]. It bases on the concepts and theories of biological ecology and uses the methods and theories of multi-disciplinarity to research various industrial ecology phenomena and their causes, thus further grasping the law of industry development and revealing industry development trend and direction[6]. Meanwhile, it is the reconstruction of ecological approach for industry theory. The second aspect is applied research reposing on Industrial Metabolism and Material Flow Analysis, among which the construction research of industrial symbiosis system--- Eco-industrial Park is the most representative one[7-8]. Industrial Metabolism research is mainly about establishing table of material balance to measure and calculate Material Flow, storage volume, and their chemical and physical state, then describing route and dynamical mechanism of Material Flow and storage volume [9]. In recent years, scholars from Netherland and England research features of industrial symbiotic network from the perspective of complex system theory and try to establish model to discuss market, technology, and policy's influences on ecological industrial development. Overall, the present industrial ecology emphasizes closed cycle of material and lays particular stress on ecological technical method. Meanwhile, it does not probe into evolution law, innovation mechanism, and development path of industrial ecology from perspectives of wholeness and systematic qualities.

B. The theory of co-evolution

The theory of co-evolution is an important theory in evolutionary biology. It firstly originates from P.H.Ehrlich and P.Raven's research on the interaction relationship between butterflies and plants. In 1980, D.H.Janzen gave a definition to co-evolution: a certain feature of a biological object can be seen in another biological object, and the feature of the latter can also respond to that of the former. Namely, co-evolution is the co-adapted evolution which is developed in the process of evolution between two interactional biological objects. The theory of co-evolution

holds the idea that creatures can compete with each other and restrict each other. However, they also cooperate with each and benefit each other. Different creatures compete for resources to live and develop. Meanwhile, they have cooperation and coexistence to save resources and achieve the balance of survival between each other and sustainable development in a certain time and space [10].

In the 1990s, the theory of co-evolution in ecology was formally introduced into economic management. James F Moore (1993) proposed that every enterprises should co-evolve with their environments instead of just competing and cooperating, or only caring about their own evolutions. At present, researches on co-evolution in economic management mainly focuses on concept of co-evolution (Futuyama&Slatkin，1983；Christopher & Richard, 1997; Jouhtio, 2006), dynamic mechanism of co-evolution (Barnett ect., 1994; Lewin &Volberda, 2003; Henderson & Ster; 2004), and application of co-evolution (Rosenkopf & Tushman, 1994; Guerrieri & Pictrobelli, 2004; Garavaglia & Breschi, 2009). Regarding enterprise and industrial cluster as an ecosystem, then researching enterprise growth and industrial cluster development with the theory of co-evolution becomes a hot topic of economy and administration. Nevertheless, there is no research on the innovation system of automobile industrial cluster from the perspective of co-evolution [11].

The ecological development of technological innovation is the key to achieving industrial ecology. In biology, the characteristic expression of technology development is technology evolution. The technology innovation system of automobile industrial cluster is an organic technology innovation cluster consisting of interrelated automobile enterprises, institutions of higher learning, scientific research institutions, and intermediary service institutions. It is an interactional and interdependent social ecosystem. The behavior of technological innovation of automobile enterprise cluster is similar to the behavior of biotic population. In the innovation ecosystem of automobile industrial cluster, we not only have to analyze each parts and their functions in this system and figure out the interdependent relationship in it, but also we have to identify the resource competition mechanism and the logical relationship seriously influencing the whole system. That is to say, we have to seek out the innovative impetus in the cluster from the perspective of the whole ecosystem [12-13].

This thesis likens the innovation system of automobile industry to natural ecosystem, thereby establishing the innovation ecosystem of automobile industry to do in-depth research on its inscape, inner mechanism of development, and mode of action. According to industrial ecology and the theory of co-evolution, the mathematical model of co-evolution innovation mechanism under the relationship of non-predation competition, the mathematical model of co-evolution innovation mechanism under the relationship of proto-cooperation, and the mathematical model of co-evolution innovation mechanism under the relationship of commensalism are established to describe the enterprises' relationship in the innovation system of automobile industrial cluster. These three models are applied to explore dynamic mechanism and implementation path of automobile industry's ecological development and guide coordinated development of automobile industry, formulation of industrial policy, and harmonious development between automobile industry and the society.

II. THE INNOVATION ECOSYSTEM OF AUTOMOBILE INDUSTRY CLUSTERS

A. Definition of the innovation ecosystem of automobile industrial cluster

With one leading industry as the core, the continuous innovation ecosystem of automobile industrial cluster has a large number of closely contacted innovation organizations and the related supportive environmental elements gathering in a particular space. These organizations and elements interact with each other and constantly promote technology innovation, knowledge innovation, organization innovation, and system innovation, then they form a self-organized and adjustable innovative network system. The innovation ecosystem of automobile industrial cluster mainly consists of innovation subject, innovation auxiliary institution (provider of innovation elements), and innovation environment. In essence, it is an interactional innovation ecological network system creating, reserving and transferring knowledge, skills, and new products. The innovation subjects include whole vehicle enterprise, integrated component enterprise, and a large number of small and medium-sized auto parts enterprise, which are the key elements of the innovation ecosystem of automobile industrial cluster. Each of them have different functions and advantages, thus forming a pyramid structure with the large whole vehicle enterprise as the dominance leading the collaborative innovation of small and medium-sized auto parts enterprises. On the one hand, this ensures the optimized information flow and knowledge flow in the cluster can be used by the innovative subjects. On the other hand, it guarantees that there can be enough sources of information flow and knowledge flow. Therefore, the information flow and knowledge flow can be expanded in the cluster. The innovation auxiliary institutions include government, all kinds of industry associations, universities, research institutes, intermediary agencies, talent training institutions, financial institutions, legal service agencies, and finally the market [14]. Automobile industry owns the features of capital denseness and high technical content, which require it have plenty of suppliers of innovation elements in the process of innovation, like scientific and reasonable industrial development policy, perfect institutional environment, abundant human resources, knowledge reserve, all kinds of technical consultation, and financial and law service, etc. [15]. The perfect and efficient intermediary agencies and auxiliary institutions can realize the above functions. The innovation environment include economic environment, political environment, legal environment, and the humanity factor affecting innovation. The innovation capacity in the cluster is not only related to

the innovation capacity of the enterprises and institutions, it is also closely correlated with the innovation environment of the region in which the cluster exist. For example, under the policy guidance and legal constraints, the policies and regulations for vehicle safety, energy conservation, and environmental protection issued by the government will lead, motivate and force the enterprises to use new energy, new materials, new technology, new business model to develop and sale new vehicle model and new product.

At the same time, in the process of innovation, the innovation subject, innovation auxiliary institution, and innovation environment in the innovation ecosystem of automobile industrial cluster will have complicated interplay. The change of one field can trigger the change of another field, which can cause constant and new interactional circulation. The pressure of competition, potential pressure, and constant comparison in the cluster constitute the sustainable innovatory motive force.

B. The co-evolution forms in the innovation ecosystem of automobile industrial cluster

The co-evolution forms of different species in the nature include prey-competition, non-predation competition, mutualism, commensalism, and proto-cooperation [16]. Table 1 presents the main co-evolution forms and connotation of the ecosystem and the innovation ecosystem of automobile industrial cluster .

Table 1. The main co-evolution forms and connotation of the ecosystem and the innovation ecosystem of automobile industrial cluster

Evolutionary type		Ecosystem	The innovation ecosystem of automobile industrial cluster
Among species	Prey-competition	The predator increases the efficiency of preying, and the prey improves the efficiency of escaping the predator. The predator and the prey have mutual promotion and co-evolution.	——
	Non-predation competition	No predation, just common competition. Two species promote each other and co-evolve.	Enterprises or organizations compete for the same innovation resources. There is no cooperation just the synergetic development.
	commensalism	Two species interact with each other. One species' making profit does not affect the other. he cooperation between them is loose, and they can separate from each other.	Enterprises or organizations compete for the same innovation resources. They have cooperation, but they can be separate from each other. If one thing is good to party B, it does not influence party A.
	mutualism	Two species rely on each other. Both of them can get benefit. Their cooperation is very tight, and they cannot separate from each other.	——
	protocooperation	Two species cooperate with each other and are beneficial to each other. The cooperation between them is loose, so they can be separated.	Enterprises or organizations compete for the same innovation resources. They have cooperation, which is good to both sides. But they also can separate from each other.

The automobile industrial cluster belongs to the collaborative cluster. The enterprises which have specialization and cooperation in materials and components and parts form the cluster. When the innovation organizations in the automobile industrial cluster compete for innovation resource, this competition is not the predation of "only one can survive". Instead, this is the common competition which does not involve predation [17]. In competition, they can affect each other and co-evolve. Moreover, there is cooperation between the upstream and downstream enterprises in the domestic and overseas automobile industrial clusters, but strictly speaking, this kind of cooperation is not equal to the absolute interdependence among different species in ecology. Therefore, there does not exist mutualism in the innovation ecosystem of automobile industrial clusters. Instead, the three main forms are non-predation competition, commensalism, and proto-cooperation.

Under the pattern of non-predation competition, the automobile enterprises in the cluster compete for innovation resource. However, in the process of competition, they also promote each other, thus helping each other adapt to the pressure of competition. In the present automobile industrial park, this is a widely existed development pattern of synergic competition. Under the pattern of commensalism, cooperation between enterprises can be beneficial to one side while it neither brings benefit nor harm to the other side. This is very common in regional automobile industry cluster. By cooperating with big companies, small enterprises or weak enterprises can improve their innovation ability, technology, and management level effectively. Nonetheless, this kind of cooperation does not drive the big enterprises' development in a large scale. After separated from each other, both of them can achieve development independently. Under the pattern of proto-cooperation, the enterprises in the cluster form a tight and mutually beneficial cooperation alliance. They draw on each other's

strength and share resources to achieve the 1+1>2 effect in collaborative innovation. Meanwhile, each enterprises can be relatively independent in this cooperation alliance. Consequently, they can have the ability of independent existence even though the alliance is dismissed. The pattern of proto-cooperation is an innovation pattern when the automobile industrial cluster becomes relatively mature. Renault-Nissan, Volkswagen, Porsche, Suzuki, Fiat, Chrysler, and PSA all adopt this pattern. Take Renault-Nissan for example, the alliance achieves prominent synergistic effect in research and development of new technology, which enables both of them expand the market and consolidate old market at the same time. This pattern improves the profitability of both sides and achieves win-win[18-19].

In the evolution of the innovation ecosystem of automobile industrial cluster, various parts in this system have cooperative behaviors. Actually, this cooperative behavior is the requirement for the evolution of the system. Different institutions and organizations in the cluster compete with each other and restrict each other. However, they also cooperate with each and benefit each other. They get resources to survive and develop through competition. Meanwhile, they cooperate with each other and coexist to save resources and achieve the balance of survival between each other and sustainable development in a certain time and space [20]. The enterprises in the cluster can exist and develop by co-adaptation and co-evolution with the lowest cost. Every enterprises is short of resource which is naturally own by themselves. If they put too much fund into extending factory building, purchasing equipment, and productivity improvement to expand scale, the research and development and innovation will be limited, which will result in insufficient capacity for further development. This can be one of the main reasons to low price competition of homogeneous product for a large number of small and medium-sized auto parts enterprises in the automobile industrial cluster lacking of innovation capacity [21-22].

Automobile industrial cluster innovation with co-evolution as premise promotes the overall development of clustering innovation capability. Co-evolution is conducive to strengthening the building of clustering innovation capability and the sustainability of development. Researching innovation mechanism of automobile industrial cluster from the perspective of co-evolution in ecology will provide more scientific, more reasonable, more sustainable, and more ecologically healthy thoughts and proofs to the formulation of industrial development policy, regional development policy, and enterprise development program and target.

III. THE INNOVATION MECHANISM OF AUTOMOBILE INDUSTRIAL CLUSTERS BASED ON THE CO-EVOLUTION AMONG POPULATIONS

The model in the modern ecology is the Logistic model predicting single population growth. Based on this classic model, this thesis establishes the innovation mechanism model of institution and organization in the automobile industrial cluster. In the innovation ecosystem of automobile industrial cluster which has limited resource, the structure development of every innovation organization is restrained by the scarce innovation resource, such as capital, technology, and market, etc. The structure development or growth can reach to the saturation level or the limit to growth, and the scarce innovation resource in the system decides the limit to growth. Therefore, the innovation growth of a single innovation population in the innovation ecosystem of automobile industrial cluster follows the Logistic law.

$$\frac{dN}{dt} = rN(1 - \tag{1}$$

In formula (1), N is the innovation output value of a single innovation organization within the time of t. r represents the inherent growth rate of innovation output of the innovation organization. r is the intrinsic growth rate of enterprise ecological effect. r is related to the intrinsic property of the industry. So r can be the constant in the dynamic operation of the innovation ecosystem of automobile industrial cluster. K is the maximum innovation output of the innovation organization when the resources are fully used. $\left(1 - \frac{N}{K}\right)$ is the Logistic coefficient which plays the braking effect in innovation output in the innovation organization. Consequently, it can always make the population quantity be compatible with the environmental capacity, thus forming a S-shape growth curve (figure 1).

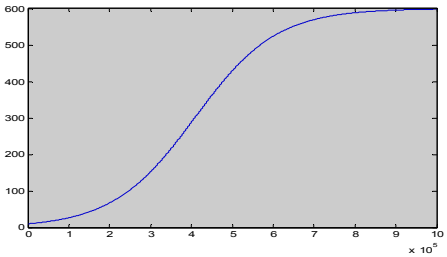

Figure 1 The innovation capacity growth model of a single population in the automobile industrial cluster

A. The co-evolution innovation mechanism under the model of non-predation competition

It is assumed that n_1 and n_2 are two innovation organizations in one automobile industrial cluster, and the independent existence and development of both of them follow the Logistic law. Under the model of non-predation competition, since n_1 and n_2 have competition in consuming the innovation resource in the cluster, both of them can impede each other. Therefore, based on the Logistic model, the Lotka-Volterra model of innovation capacity growth under the model of non-predation competition for n_1 and n_2 can be established.

$$\begin{cases} \frac{dN_1}{dt} = r_1 N_1 \left(1 - \frac{N_1}{K_1} - \alpha \frac{N_2}{K_1}\right) = f(N_1,\ N_2) \\ \frac{dN_2}{dt} = r_2 N_2 \left(1 - \frac{N_2}{K_2} - \beta \frac{N_1}{K_2}\right) = g(N_1,\ N_2) \end{cases} \tag{2}$$

N1 and N2 are the innovation output value of n_1 and n_2 respectively. r1 and r2 are the natural growth rates of innovation output for n_1 and n_2. K1 and K2 represent the maximum innovation output when the resources are fully used. α （β）is the suppressing coefficient of innovation capacity growth of n2 (n1) to n1（n2）. α （β） is in direct proportion to the present innovation capacity of n2 (n1) and in inverse proportion to the maximum innovation capacity of n1（n2）. It shows that in the present cluster environment, the innovation resources which can be used by n_2 (n_1) are not only related to its own biggest innovation potential but also connect with the applying ability of the competitor, n_1 (n_2), in using the innovation resources of the same kind.

Make $f(N_1, N_2)=0$, $g(N_1, N_2)=0$, then:

$$\begin{cases}\left(1-\frac{N_1}{K_1}-\alpha\frac{N_2}{K_1}\right)=0\\ \left(1-\frac{N_2}{K_2}-\beta\frac{N_1}{K_2}\right)=0\end{cases} \quad (3)$$

According to formula 3, we can get 4 growth models which are shown from figure 2-1 to figure 2-4. And these 4 models correspond with the 4 co-evolution innovation situations under the model of non-predation competition of N1 and N2 in table 2.

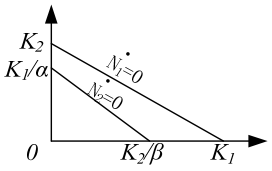

Figure2-1
(Situation 1)

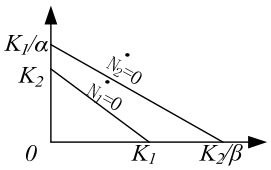

Figure2-2
(Situation 2)

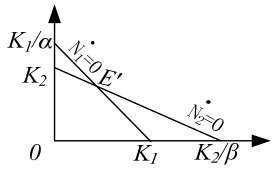

Figure2-3
(Situation 3)

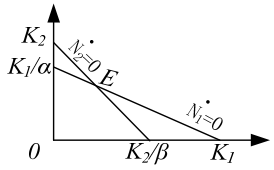

Figure2-4
(Situation 4)

Solving equations, 4 equilibrium points, P1（0，0），P2(K1，0)，p3(0，K2)，P4($\left[\frac{(1-\alpha)}{1-\alpha\beta}K_1, \frac{(1-\beta)}{1-\alpha\beta}K_2\right]$ can be got. As N1 and N2 cannot be zero, P1, P2, and P3 do not have practical significance. Therefore, P4 is the only right equilibrium point. That is to say, the equilibrium point coordinate of innovation capacity growth for n1 and n2 is like this: $\left[\frac{(1-\alpha)}{1-\alpha\beta}K_1, \frac{(1-\beta)}{1-\alpha\beta}K_2\right]$.

TABLE 2 CO-EVOLUTION INNOVATION SITUATIONS UNDER THE MODEL OF NON-PREDATION

Condition		Situation 1	Situation 2	Situation 3	Situation 4
K1/α 1 2< K2	K2/α 21< K1	——	——	Both N1 and N2 may win.	——
	K2/α 21> K1	——	N2 always win.	——	——
K1/α 1 2> K2	K2/α 21< K1	N1 always win.	——	——	——
	K2/α 21> K1	——	——	——	Stable coexistence

According to formula(2), picture 3 , and table 2, the co-evolution innovation mechanisms under the model of non-predation competition for n_1 and n_2 are as follows:

(1) When α =0 and β =0, n1 and n2 are not correlative with each other in innovation resources utilization, and they follow the Logistic law to grow respectively. Finally they reach the equilibrium state, N1and N2, and just fluctuate after the peak. At this time, the organizations in this cluster are just close to each other geographically and do not produce any synergistic effect. Moreover, when these organizations compete for innovation resources and regional advantages, the whole innovation capacity of the automobile industrial cluster is reduced. The automobile industrial cluster is not just the simple gathering of a large number of enterprises. The important thing is that the organizations in the same cluster can form the relationship of close cooperation to make the most of the collaborative innovation advantages of the enterprises in the cluster. As a consequence, in formulating the regional development policy of the automobile cluster, the assessment criteria of the automobile enterprises entering the automobile industrial park both before and after should be strictly formulated to build the resultant development force of innovation.

(2)When K1/α 12> K2 and K2/α 21< K1, n2 is weaker than n1 in fighting for the innovation resources. Moreover, n1 is still stronger than n2 in competing for the innovation resources of n2. As a result, the contour line of n1 is always over that of n2(figure 2-1, situation 1 in table2). n1 owns the absolute advantage in fighting for the innovation resources with n2. As this time, it reaches balance at the point of P2（K1，0）. On the contrary, when 1/α 12< K2 and K2/α 21>K1, the contour line of n2 is always over that of n1(picture 2-2, situation 2 in table 2). n2 owns the absolute advantage in fighting for the innovation resources with n1, then reaches balance at the point of P3（0，K2）.

(3) When K1/α 12< K2 and K2/α 21< K, two contour lines meet in a point of E′(figure 2-3, situation 3 in table 2). At this time, both n1 and n2 may win, and both of them can control each other. However, the equilibrium point is not stable, and these two innovation organizations are at the unstable state of competition. The condition of stable equilibrium is N2=K2 and N1=0 or N1=K1 and N2=0. The use quantity ratio of the original resources of n1 and n2 will decide who will win.

(4) When K1/α 12> K2and K2/α 21> K1 , two contour lines meet in a point of E(figure 2-4, situation 4 in table 2). At the stable equilibrium point P4($\left[\frac{(1-\alpha)}{1-\alpha\beta}K_1, \frac{(1-\beta)}{1-\alpha\beta}K_2\right]$),

n1 and n2 cannot control each other, but the equilibrium point is stable. And these two innovation organizations are at the unstable state of competition.

B. The co-evolution innovation mechanism under the model of commensalism.

Under the model of proto-cooperation, since organization n1 and n2 have mutual promotion in the growth of innovation capacity, the innovation capacity growth model under the model of proto-cooperation for n1 and n2 can be established based on formula 2.

$$\begin{cases} \frac{dN_1}{dt} = r_1 N_1\left(1 - \frac{N_1}{K_1} + \alpha\frac{N_2}{K_1}\right) = f(N_1, N_2) \\ \frac{dN_2}{dt} = r_2 N_2\left(1 - \frac{N_2}{K_2} + \beta\frac{N_1}{K_2}\right) = g(N_1, N_2) \end{cases} \quad (4)$$

Sharing the principle of 3.1.1, when $f(N_1, N_2) = 0$ and $g(N_1, N_2) = 0$, the stable equilibrium point of innovation efficiency under the model of proto-cooperation for n1 and n2 is P4$\left(\frac{(1+\alpha)}{1-\alpha\beta}K_1, \frac{(1+\beta)}{1-\alpha\beta}K_2\right)$.

(1) When α =0 and β =0n1 and n2 are not correlative with each other in innovation resources utilization, and they follow the Logistic law to grow respectively, just like the situation of (1). Even though they are close to each other geographically, they do not contact with each other, and the cooperation effect is zero. That is to say, the organizations in the cluster are at the state of self-organized development.

(2) When α <1, β <1, and $\alpha\ \beta$ <1, there are some contacts and cooperation between n1 and n2, but these contacts and cooperation are not tight. This is the beginning of collective cooperation. under such circumstances, the trust, reciprocal bond, and supervisory mechanism are established gradually. With the constant improvement of technology, equipped level, the experience and capability of the research personnel, the trust and contacts between the organizations are continuously strengthened. So, the cooperation space between n1 and n2 is constantly expanded. At this time, there are requirements, conditions, environment, and potential of innovation cooperation in the automobile cluster. Consequently, the government and some other coordinating organizations should research do on the development trend of automobile enterprises, play the role of coordinating promotion, and formulate and implement policies like fiscal preferential, economic subsidy, and preferential procurement, etc, to encourage enterprises to cooperate with each other actively with economic benefit.

(3) When α >1, β <1, and $\alpha\ \beta$ <1, n1 is the dominant enterprise, and n2 is the subordinate enterprise, which means that n1 drive n2 to innovate and has relatively great impact on n2. That is to say, n2 has little influence on n1 in innovation capacity building. Hence, when the government is formulating the development program and relevant policy of automobile industrial cluster, more support should be given to the core host enterprise and the key auto parts enterprises to promote the rapid development of the dominant enterprise and drive the improvement of the subordinate small and medium-sized auto parts enterprises, thus enhancing the whole innovation capacity of the cluster. However, when α <1, β >1, and $\alpha\ \beta$ >1, the situation is contrary.

C. The co-evolution innovation mechanism under the model of commensalism.

Under the model of commensalism, since organization n_2 promotes organization n_1's innovation capacity growth, but organization n_2's innovation capacity does not enhanced by organization n_1 , with formula(2), the innovation capacity growth model under the model of commensalism for n_1 and n_2 can be established.

$$\begin{cases} \frac{dN_1}{dt} = r_1 N_1\left(1 - \frac{N_1}{K_1} + \alpha\frac{N_2}{K_1}\right) = f(N_1, N_2) \\ \frac{dN_2}{dt} = r_2 N_2\left(1 - \frac{N_2}{K_2}\right) = g(N_1, N_2) \end{cases} \quad (5)$$

Make $f(N_1, N_2)$ =0 and $g(N_1, N_2)$ =0, the stable equilibrium point of innovation efficiency under the model of commensalism for n1 and n2 is P4$[K_1 + \alpha K_2, K_2]$.

(1) n_2 promotes and drives n_1's innovation resource efficiency in its innovation activity obviously. This is very common in some regions where main engine enterprises or auto parts assembly enterprises drive the development of small and medium-sized auto parts enterprises. These leading enterprises establish and shape the innovation network of automobile cluster and are crucial to the heath, innovation, and evolution of the industrial system. Under such circumstances, organization n_1 should strengthen cooperation and communication with n_2, constantly improve its innovation capability, and enhance the overall innovation level and development vitality of the cluster.

(2) For organization n_2, n_1 does not help it evidently in the utilization of innovation resource as there is a noticeable gap in innovation capacity and development level between n_1 and n_2. As a consequence, it is hard for n_1 to make a great contribution to n_2's innovation capacity growth. Nevertheless, with n_1's gradual development and growth, it will positively influence n_2 in new model development and collaborative innovation of new technology, thus developing into the innovation state under the model of proto-cooperation which generates mutual reciprocity. Therefore, in formulating regional automobile industry policy, strong enterprises should be encouraged to assist small and medium-sized auto parts enterprises which are weak in industry development but own development potential and development prospect, thereby enhancing the overall innovation strength and sustainable development level of the whole cluster.

IV. CONCLUSIONS

This paper introduces ecology and the theory of co-evolution into the research of the innovation system of automobile industrial cluster and reveals dynamic

mechanism and systematic evolutionary law of the innovation ecosystem of automobile industrial cluster. In the aspect of research method, the theory of co-evolution changes the past way of thinking which is linear and one-way causation. Instead, this thesis adopts the paradigm which is nonlinear and owns a number of causality, which is beneficial to inspecting characteristics of different parties from the complicated dynamic connection among different members, thus grasping essence of issue. In the innovation ecosystem of automobile industrial cluster, competition and cooperation of internal enterprises generate development impetus, and the overall co-evolution of the ecosystem brings about competitive advantage, then the sustainable development of the cluster can be achieved.

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