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Research on the Construction and Evolution Model of Cloud Ecosystem

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Abstract. Clarifying the positioning of participants in the cloud ecosystem and analyzing the competition and cooperation among subjects are important for the sustainable and healthy development of cloud ecosystem. This paper analyzed the structure and the evolution law of the participants in the cloud ecosystem. The results show that, in a certain degree of competitive environment, companies with different positions and competitive relationships have different competitiveness. Cooperation is conducive to the coexistence of individuals. The stronger the cooperative relationship, the greater the enterprise's profit. These findings give a beneficial motivation for the coordinated relationship and development strategy for cloud providers.

Keywords. Cloud ecosystem structure, evolution model, competition and cooperation

1. Introduction

As cloud computing development enters a period of high growth, supporting service segments such as third-party application developers, system integration, cloud consulting services become more and more important [1]. Establishing a cloud ecosystem becomes the key to cloud service provider competition. More and more companies, such as Microsoft and Google, are working together to build cloud ecosystems by expanding their business scope and cultivating partners [2-4]. Competition among enterprises in cloud industry has gradually evolved into the competition among cloud ecosystems. In relation this shift, it is an important issue to promote the development of a healthy cloud ecosystem by building a cloud ecosystem, analyzing the competing relationships of member companies in the ecosystem, and promoting the sustainable development of the cloud ecosystem.

A well-developed cloud ecosystem must be balanced and stability, which is achieved through the development and interaction of participants. Although researchers have mentioned the interrelationship between enterprises in cloud ecosystem, there is no clear answer the interactive relations and deep research on evolution law among the participants. Therefore, the paper analyses the structure of cloud ecosystem, establishes the evolution model for the participant's cooperation and competition. Finally, taking the

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CPs in Ali cloud ecosystem as an example for empirical analysis, this paper explores the evolution mechanism by simulation. Through the understanding of the internal membership and the evolution mechanism of cloud ecosystem, the relationship among members can be better coordinated, the healthy development strategy of ecosystem can be formulated and maintained.

2. Related Works

Many scholars have extended the concept of business ecosystem from traditional industries to the emerging cloud computing industry, and put forward different perspectives on the cloud ecosystem [5-9]. The University of Melbourne research team believed that there are multi-CPs and multi-tenants (cloud users) in the cloud market [1]. Gupta and others regarded cloud ecosystem as the resource sharing ecosystem among cloud providers [6]. Kushida et al. proposed a "cloud service framework" analysis tool which includes two dimensions of provider type and cloud architecture layer [9]. From a market view, Kushida K E summarized the cloud ecosystem into three key components: the demand side (individual, organization, and enterprise users), the cloud (IaaS, PaaS, and SaaS) and the provider [9]. Deng et al. put forward the value structure model of cloud ecosystem, which is composed of CPs, agencies, consumers and external environment [4]. In the evolution of cloud ecosystems, scholars have conducted studies from the perspective of cooperation and competition [10-13]. In the early stage of cloud ecosystem formation, usually multiple subjects choose to cooperate among themselves to build a dynamic cloud ecosystem with a generic value network to jointly provide high-value cloud services to users [11], while Paya et al. argue that cooperation among subjects in a cloud ecosystem can reduce the cost of energy consumption for both parties [12]. Subramanian et al considered the elasticity of cooperation between logistics and cloud providers from the perspective of innovation diffusion [13]. As cloud computing ecosystems grow and evolve, competition becomes more intense [2].

At present, the research on the evolution and internal mechanism of cloud ecosystem is mainly carried out from the qualitative point of view, lacking the construction of mathematical models. Therefore, this paper explores the sustainable development law of cloud ecosystem by constructing a framework of cloud ecosystem and analyzing the dynamic competition and evolutionary game relationship between multiple subjects.

3. The construction of cloud ecosystem

Cloud computing ecosystem is subordinate to business ecosystem, which is the expansion and extension of business ecosystem theory in cloud computing industry, so cloud ecosystem also has the general structure of traditional business ecosystem. This paper uses Moore's business ecosystem structure model, combined with the characteristics of the cloud computing industry chain, to divide the cloud ecosystem into five parts: core cloud ecosystem, extended cloud ecosystem, competitive system, support system and environmental system.

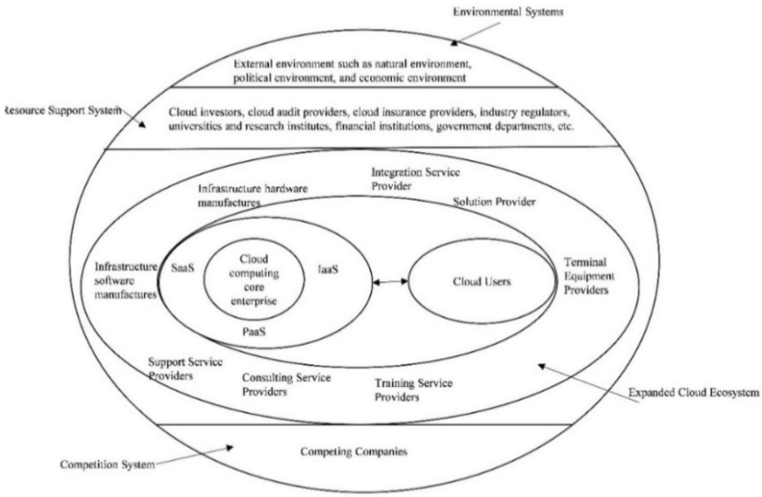


Figure 1. The structure of Cloud ecosystem

As shown in Figure. 1, in the cloud ecosystem structure model, the core cloud ecosystem is generally built by a certain core cloud computing enterprise or platform, which is the core layer of the cloud ecosystem and dominates the development direction of the whole ecosystem. After the core cloud ecosystem matures, it attracts a large number of upstream and downstream enterprises to join the ecosystem, gradually forming a broader range and richer species of extended cloud ecosystem, which is a supplement and extension of the core cloud ecosystem, and the two together build the core business system of the cloud ecosystem. The resource support system provides the basic resources needed for the survival of the cloud ecosystem, and is an important support for the core business. The development of the cloud ecosystem is also inseparable from the support of the external environment. The environmental system is the basis for enterprises to provide services to users, and provides environmental and spatial support for enterprises in the ecosystem

4. The Evolution Model of Competition and Cooperation of Main Enterprises

The main enterprises of the cloud ecosystem cooperate and interconnect with each other to provide users with high-quality, high-value cloud services and jointly promote the development and evolution of the cloud ecosystem. This paper establishes the evolution model of subject interaction in the cloud ecosystem based on the competing symbiotic relationship. Here, the evolution model of competition and cooperation between CP A and B can be shown as follows

$$\begin{aligned} \frac{dy_1}{dt} &= r_1 y_1 \left(1 - \frac{y_1}{K_1} - \frac{\alpha_{12} y_2}{K_2} + \frac{\beta_{12} y_2}{K_2}\right) \\ \frac{dy_2}{dt} &= r_2 y_2 \left(1 - \frac{y_2}{K_2} - \frac{\alpha_{21} y_1}{K_1} + \frac{\beta_{21} y_1}{K_1}\right) \end{aligned} \tag{1}$$

α_{12} , α_{21} refer to the competition coefficient, β_{12} , β_{21} present the cooperation coefficient.

Here, let set $c_{12} = \alpha_{12} - \beta_{12}$, $c_{21} = \alpha_{21} - \beta_{21}$, c_{12}, c_{21} refer to the coincidence coefficient, so the Eq(3) can be transferred into :

$$\begin{aligned} \frac{dy_1}{dt} &= r_1 y_1 (1 - \frac{y_1}{K_1} - \frac{c_{12} y_2}{K_2}) \\ \frac{dy_2}{dt} &= r_2 y_2 (1 - \frac{y_2}{K_2} - \frac{c_{21} y_1}{K_1}) \end{aligned} \tag{2}$$

According to the evolution model, when the competition and cooperation of enterprises A and B reach to the balance, the equation is as follows:

$$\begin{aligned} \frac{dy_1}{dt} &= r_1 y_1 (1 - \frac{y_1}{K_1} - \frac{c_{12} y_2}{K_2}) = 0 \\ \frac{dy_2}{dt} &= r_2 y_2 (1 - \frac{y_2}{K_2} - \frac{c_{21} y_1}{K_1}) = 0 \end{aligned} \tag{3}$$

Therefore, the contours of the change rate of service transaction volume of enterprises A and B respectively are obtained.

$$L_1 : 1 - \frac{y_1}{K_1} - \frac{c_{12} y_2}{K_2} = 0 \, , L_2 : 1 - \frac{y_2}{K_2} - \frac{c_{21} y_1}{K_1} = 0$$

Here, the coefficients of competition and cooperation c_{12}, c_{21} are different, enterprises A and B also show different evolution results. So, the evolution models of competition and cooperation between A and B under different conditions are discussed separately.

Case 1: $c_{12} = 0, c_{21} = 0$

When $c_{12} = 0, c_{21} = 0$, the negative effects of competition and the mutually beneficial effects of cooperation offset each other. It indicates that in the process of competition and cooperation, the evolution of the niche of enterprises A and B follows the Logistic law. Both enterprises make the best use of resources, then the equilibrium state equation is established.

$$\begin{aligned} \frac{dy_1}{dt} &= r_1 y_1 (1 - \frac{y_1}{K_1}) = 0 \\ \frac{dy_2}{dt} &= r_2 y_2 (1 - \frac{y_2}{K_2}) = 0 \end{aligned} \tag{4}$$

As shown in Figure. 2, the equilibrium point $E(K_1, K_2)$ is the best symbiotic point of the two enterprises. The result of the competition and cooperation shows that the niche of them is adjacent and coexists with their maximum niche breadth, namely, both enterprises reach their maximum service transaction volume K_1, K_2.

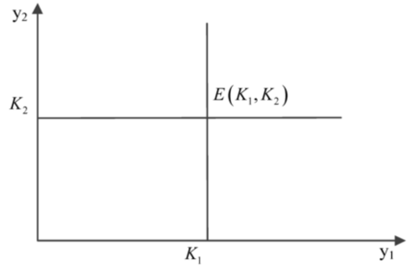


Figure.2. Case 1: The equilibrium state of the evolution model of the competition and cooperation when $c_{12}=0$, $c_{21}=0$

Case 2: $c_{12}=0$, $c_{21}>0$ **or** $c_{12}>0$, $c_{21}=0$

When $c_{12}=0$, $c_{21}>0$, for enterprises A, the negative effects of competition and the mutually beneficial effects of cooperation with enterprises B offset each other. Enterprises A can maximize the use of resources to reach the upper limit of service transaction volume. For enterprises B, the negative effects of competition caused by partial niche overlap are greater than the mutually beneficial effects. Consequently, the niche breadth of enterprises B is decreasing. Thus, the growth rate of service transaction volume is decreasing. However, the evolution model has two equilibrium states according to the different value ranges of the service transaction volume.

1) When $c_{21}>1$, the result shows in Figure.3 (a). The final result of competition and cooperation is that the niche breadth of enterprise A occupies the enterprise B's. The bigger the resource utilization of enterprise A, the bigger the coefficient of competition and cooperation of enterprise B. Enterprise A is more likely to be in a dominant niche in competition symbiosis. Its balance point is $(K_1,0)$, but the two enterprises can not reach a symbiotic balance.

2) When $c_{21}<1$, the result shows in Figure.3 (b). The niche breadth of enterprise A remains unchanged while the enterprise B's decreases continuously. Under this condition, the smaller the competition coexistence coefficient is, the more conducive to the coexistence of the two enterprises are. Thus, the symbiotic equilibrium point is $E(K_1,K_2-c_{21}K_2)$. This symbiotic state has no effect on enterprise A while is harmful to enterprise B, so it is a symbiotic state of partial harm.

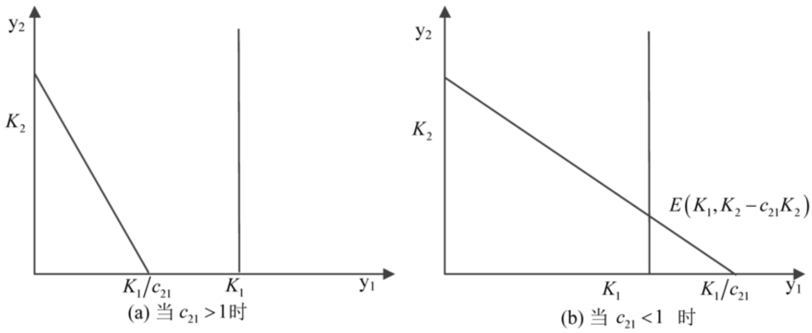


Figure.3 Case 2: The equilibrium state of the evolution model of the competition and cooperation when

$$c_{12}=0, c_{21}>0$$

If $c_{12}>0, c_{21}=0$,the model is similar to the above situation, and the paper will not discuss it here.

Case 3: $c_{12}=0, c_{21}<0$ or $c_{12}<0, c_{21}=0$

If $c_{12}=0, c_{21}<0$, the result shows in Figure.4. The negative effect of competition and the effect of cooperation between B and A offset each other, while the effect of cooperation between enterprise A and B is greater than the negative effect of competition. Therefore, the niche breadth of enterprise A keeps unchanged, while the enterprise B's keeps increasing, and the growth rate of service transaction volume keeps increasing. Finally, the two enterprises reach a symbiotic state, and their symbiotic equilibrium point is $E(K_1, K_2-c_{21}K_1K_2)$. This symbiotic state has no influence on enterprise A and is beneficial to enterprise B, so it is a symbiotic relationship of preference and benefit.

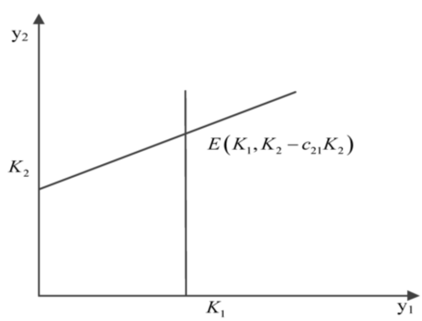


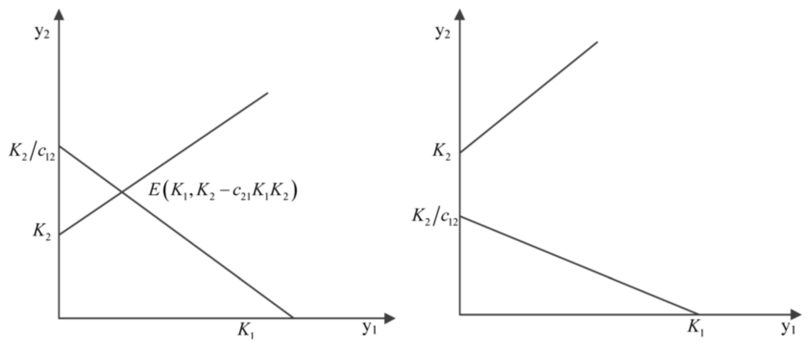
Figure.4 Case 3:The equilibrium state of the evolution model of the competition and cooperation when

$$c_{12}=0, c_{21}<0$$

If $c_{12}<0, c_{21}=0$, the model is similar to the above situation, and the paper will not discuss it in detail here.

Case 4: $c_{12} > 0, c_{21} < 0$ or $c_{12} < 0, c_{21} > 0$

If $c_{12} > 0, c_{21} < 0$,for enterprises A, the negative competition effect caused by partial niche overlap is greater than the mutually beneficial effect caused by cooperation. Therefore, the resources used by enterprises A are decreasing, the niche breadth is decreasing, and the growth rate of service transaction volume is decreasing. However, the effect of cooperation between enterprises A and B is greater than the negative effect of competition. So, the niche breadth of enterprise A remains unchanged, while that of enterprise B keeps increasing. For enterprise B, the utilization of resources continues to increase, and the growth rate of service transaction volume continues to increase. The equilibrium state of the competitive and cooperative has two conditions according to the different value ranges of the service transaction volume.



(a) $K_2 < 1/c_{12}$ (b) $K_2 > 1/c_{12}$

Figure.5 Case 4:The equilibrium state of the evolution model of the competition and cooperation when $c_{12} > 0, c_{21} < 0$

1) When $K_2 < K_2/c_{12}$,as shown in Figure.5 (a), the initial service transaction volume of Enterprise A is larger than that of B. While the niche breadth of enterprise A decreases and enterprise B uses part of the resources of enterprise A to increase the niche breadth, the niche of the two enterprises is separated to achieve the competitive symbiosis equilibrium point, and the two enterprises realize the symbiosis state $E(K_1, K_2 - c_{21}K_1K_2)$. This symbiosis state is harmful to enterprise A and beneficial to B, so it is a similar predatory or parasitic relationship.

2) When $K_2 > K_2/c_{12}$,as shown in Figure. 5.(b), enterprise B's niche increased continuously. The greater the competition coefficient for enterprise A, the further occupied the niche of enterprise A. The increasing service transactions volume of B was achieved at the expense of enterprise A's resources, so the two could not achieve a symbiotic balance.

If $c_{12} < 0, c_{21} > 0$, the model is similar to the above situation, and the study will not discuss it here.

Case 5: $c_{12} > 0, c_{21} > 0$

When $c_{12} > 0, c_{21} > 0$, the negative effect of competition between the two enterprises is greater than the mutually beneficial effect of cooperation.

When $K_1 > K_1/c_{21}$, $K_2 < K_2/c_{12}$, the enterprise A is in the dominant niche in the competition and cooperation between the two enterprises. By occupying the niche of enterprise B, enterprise A finally reaches the equilibrium point $(K_1, 0)$. However, when enterprise B is eliminated, the two enterprises can not achieve symbiosis.

When $K_1 < K_1/c_{21}$, $K_2 > K_2/c_{12}$, enterprise B wins in the competition symbiosis and finally reaches the balance point $(0, K_2)$. However, when enterprise A is eliminated, the two enterprises can not achieve symbiosis. $(0, K_2)$.

When $K_1 > K_1/c_{21}$, $K_2 > K_2/c_{12}$, The niche overlap of the two enterprises is relatively large, showing a strong competitive relationship. Enterprises with competitive advantages want to occupy the niche of another enterprise, and the two are not mutually compatible. $(K_1, 0)$ and $(0, K_2)$ is the maximal goal of the service transaction volume sought by enterprises A and B. Therefore, the two enterprises can not achieve the symbiotic state and may win in the unstable competitive symbiotic state.

When $K_1 < K_1/c_{21}$, $K_2 < K_2/c_{12}$, both A and B enterprises are in a weak competitive state, and they can reach a symbiotic equilibrium, with a symbiotic equilibrium point of $E\left(\frac{(1-c_{12})K_1}{1-c_{12}c_{21}}, \frac{(1-c_{21})K_2}{1-c_{12}c_{21}}\right)$.

Case 6: $c_{12} < 0, c_{21} < 0$

If $c_{12} < 0, c_{21} < 0$ the mutual benefit effect of the cooperation between A and B is greater than the negative competition effect. The two enterprises pay more attention to the coordination and cooperation through resource sharing and complementary advantages. As a result, the niche breadth of each other is increasing. The growth rate of resource utilization and service transaction is increasing. The niche separation degree is greater than their overlap degree. The two enterprises realize mutually beneficial symbiosis, and their symbiosis equilibrium point is $E\left(\frac{(1+c_{12})K_1}{1-c_{12}c_{21}}, \frac{(1+c_{21})K_2}{1-c_{12}c_{21}}\right)$

5. The simulation analysis for the evolution model in cloud ecosystem

Here, we assume that there are six representative CPs from a cloud ecosystem. Then, the evolution model of competition and cooperation for the enterprises are simulated by using MATLAB.

Scenario 1:Competitive Evolution

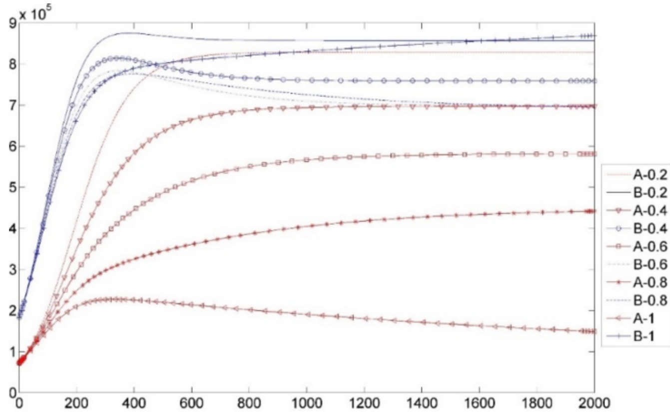


Figure 6. Individual evolutionary trends of service providers with different competition coefficients

From Figure.6, it can be seen that the initial state and ecological niche width of cloud service provider B within the cloud ecosystem are more advantageous compared to A. Therefore, cloud service provider B has ecological niche advantage compared to A. Comparing and analyzing the development evolution trend of cloud service provider A and B under the change of competition coefficient, cloud service provider A and B reach the maximum service transaction volume respectively when the mutual competition between enterprises within the ecosystem is the weakest. With the increase of competition coefficient, the competition between cloud service providers A and B for resources within the ecosystem intensifies, and the change of competition factors within the ecosystem has less impact on B with ecological niche advantage, while it has a significant impact on the development evolution of A.

Scenario 2: Cooperation Evolution

As shown in Figure.7, cloud service providers B and D form complementary advantages and value co-creation through mutually beneficial cooperation, and then reach a mutually beneficial symbiotic state, and the actual service transaction volume of both cloud service providers exceeds the upper limit of their service transaction volume in normal state. From the evolution process of individual cloud service providers under the cooperation mode, the initial state of the individual has an important role in the early development of the individual, while the role is not obvious in the late development and evolution of the individual. When the cooperation coefficient is 0.2, 0.4, 0.6, and 0.8, the trend of the development and evolution of cloud service providers B and D, the greater the cooperation coefficient between B and D, i.e., the stronger the cooperation relationship, the greater the final service transaction volume under the equilibrium state of the evolution and development of the two service providers, i.e., the greater the profit of the two cooperative enterprises.

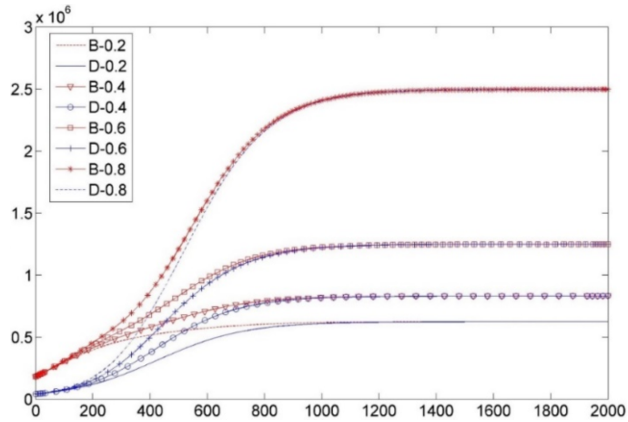


Figure 7. Individual evolutionary trends of service providers with different cooperation coefficients

Scenario3: Competition and Cooperation Evolution

As shown in Figure 8, they are gradually eliminated under the monopolistic competitive environment formed by the cooperation of A and B. The deeper the overlap between the ecological niche width and A and B, the more affected by their cooperation. The deeper the overlap between ecological niche width and A and B, the more it is affected by their cooperation, such as the overlap between E and A and B is low, so it is less affected by A and B cooperation; CP F has a higher degree of overlap than E, F, A and B, so F is more affected by A and B competition.

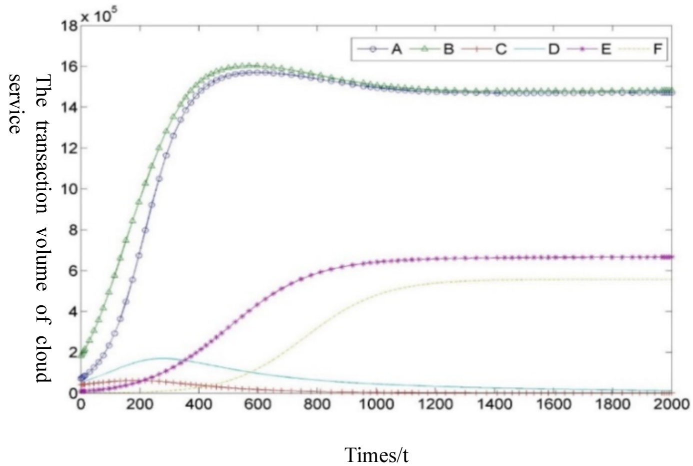


Figure.8 The Evolutionary Trend of CPs' Competition and Cooperation under the Cooperation of A and B

6. Conclusion

In this paper, we construct a cloud ecosystem structure and analyze the evolutionary model of competition and cooperation among subjects to explore the individual development laws under different circumstances. The results show that in a competitive environment, cooperation is beneficial to the coexistence and development of both participants. This paper focuses on the evolutionary mechanisms of competition and cooperation in the cloud ecosystem. However, the main firm strategies assumed in this paper are fixed, i.e., competition, cooperation, and one of the competitions. Therefore, a further study can be the evolutionary pattern of dynamic strategies of the business entities in the cloud ecosystem. Considering the influence of the transaction process, the development and change patterns under the interaction of different firms can be analyzed.

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