RESEARCH ON THE FORMATION AND EVOLUTION MECHANISM OF CHINA'S DEFENSE INDUSTRIAL CLUSTERS

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Abstract: *The evolution of China's defense industrial cluster is essentially a game of military enterprises and civil enterprises. In order to analyze the behavior of military enterprises and civil enterprises in the evolution process of defense industrial cluster, this paper construct an evolutionary model for analyzing the evolution mechanism of China's defense industry cluster based on evolutionary game theory. The results show that, in the development of China's defense industrial cluster, there are two long-run equilibriums: cooperation and non-cooperation. There are four factors have significant influence on the long-term equilibriums: profit of cooperation, distribution of cooperation profit, amount of investment and transaction cost.*

Keywords: *Defense Industry; Industrial cluster; Evolution Mechanism; Evolutionary Game Theory*

1. INTRODUCTION

As a kind of economic phenomenon, industrial cluster has been mentioned in Marshall's theory of external economy (1920) and Webb's theory of industrial location (1929). In the late 1970s, industrial cluster has gradually become a hotspot in management science, economics, sociology and other disciplines. Industrial cluster plays an important role in technology innovation, industrial structure adjustment and the establishment of regional economic agglomeration.

After years of "conversion" practice, China's defense industry has formed a large and medium-sized state-owned military enterprise accumulation area in the Midwest. Civil-military integration industrial park developed rapidly. Defense industrial cluster has entered a new stage of development.

But the current national defense industry agglomeration is formed under the guide of the government, rather than the market mechanism. The advantage of military enterprises in resources and technology has not yet fully played, and the fusion effect of defense industry and regional national economy has not been fully revealed.

Therefore, basing on current situation of China's defense industry, learning from the experience of defense industrial clusters all over the world, analyzing the mechanism of defense industrial cluster evolution and promoting the development of China's defense industrial cluster, have become an important problem urgently need to be studied.

The evolution of China's defense industrial cluster is essentially a game of military enterprises and civil enterprises. In order to analyze the behavior of military enterprises and civil enterprises in the evolution process of defense industrial cluster, this paper construct an evolutionary model for analyzing the evolution mechanism of China's defense industry cluster based on evolutionary game theory.

2. EVOLUTIONARY GAME MODEL AND THE EVOLUTIONARY CHARACTERS IN THE DEVELOPMENT OF DEFENSE INDUSTRIAL CLUSTER

The analysis in micro economic theory is mainly equilibrium analysis. The basic hypotheses are fully competitive market and rational man. In practice, due to the limitation of human cognitive ability, the individuals involved in the game are limited rational. Their decision behavior would be affected by environment, daily practices and other factors. Their strategy equilibrium is not the result of one-time selection, but the realization of learning adjustment. And equilibrium analysis is not applicable to this problem. Therefore, the paper analyzes the selection and evolution path of defense industrial cluster using evolutionary game theory based on "bounded rationality" hypothesis.

2.1 The framework of evolutionary game model

The basic hypothesis of evolutionary game model is "bounded rationality". The framework is based on Darwin's natural selection theory, which is used to research the species trait evolution and stability mechanism. "replication dynamics" in biological evolution of biological character and behavior characteristics is the main dynamic mechanism in the analysis of limited rational game, and "evolutionarily stable strategy" is the core concept.

There are two players in a game, whose names are respectively P1 and P2. Each of them has two strategies: S1 and S2. S1 is a conventional strategy and S2 is an mutational strategy. When the combined strategy of P1 and P2 is (S1, S2), their payoff are U1 (S1, S2) and U2 (S1, S2). Suppose, the probability of P1 and P2 to choose the mutation strategy is α, and the expected payoff of them Using the strategy of S1, S2 respectively are as follows:

$$(1-\alpha)u_i(s_2,s_1)+\alpha u_i(s_2,s_2) \quad (1)$$

$$(1-\alpha)u_i(s_1,s_1)+\alpha u_i(s_1,s_2) \quad (2)$$

If $\overline{\alpha}>0$, than $(1-\alpha)u_i(s_1,s_1)+\alpha u_i(s_1,s_2)=(1-\alpha)u_i(s_2,s_1)+\alpha u_i(s_2,s_2)$, and there are multiple evolutionary stable points in the game, respectively are:

$\alpha^*=0$, $\alpha^*=\overline{a}$ and $\alpha^*=1$. When $\alpha^*<\overline{a}$, the expected payoff of the player who chooses mutational strategy will be less than who chooses conventional strategy.

And the player who chooses mutational strategy will be excluded from the population, the combined strategy (S1, S1) is the equilibrium combination and the conventional strategy will be the evolutionarily stable strategy.

When $\alpha^*>\overline{a}$, the expected payoff of the player who chooses mutational strategy will be larger than who chooses conventional strategy. And the player who chooses conventional strategy will be excluded from the population, the combined strategy (S2, S2) is the equilibrium combination and the mutational strategy will be the evolutionarily stable strategy.

When $\alpha^* = \bar{a}$, the expected payoff of the player who chooses mutational strategy will be equal to who chooses conventional strategy. The ratio of members taking conventional strategy and mutational strategy will be maintained at $\bar{a} : (1-\bar{a})$.

But the ratio is not stable. Once the random factors increased the number of player choosing a certain strategy, the evolution of the group will be conducive to the team who choose this strategy, until a new equilibrium.

The basic framework of evolutionary game model shows three notable features in the process of analysis: the first, the decision behavior of individuals involved in the game would be affected not only by individual rationality, but also by environment, daily practices and other factors. They are "bounded rationality". Second, there are three important mechanisms in the process of evolution, which include mutation mechanism, selection mechanism and diffusion mechanism. That is why path dependence exists. Third, the results of evolution have multiple equilibriums, and there are several evolutionary stable points.

2.2 The evolutionary characters in the development of defense industrial cluster

Many economists believe that the industrial cluster is a phenomenon related to the concentration of industrial activities in geography or in a particular place. Defense industrial clusters is, in the field of defense, breaking the barriers between military enterprises and civilian enterprises, the agglomeration of a number of defense industry and related enterprises in a particular space. Interaction of economic agents in defense industrial cluster, mainly be seen as the game of military enterprises and civilian enterprises. And evolutionary game is a remarkable character in the course.

2.2.1 *The economic agents in defense industrial clusters are "Bounded Rational People"*

In the process of forming and evolution of the defense industry cluster, only when the expected return of cooperative behavior is higher than those in non-cooperative condition, the economic agents will choose cooperation. But the interaction between the agents in the process is complex.

The economic agents should not only consider the choice of each player's strategies when they involve in the game, but also the changes of strategies when new members engage in. In this process, many deterministic and stochastic factors in the environment may have a significant influence on individual strategies. It's not the results of one-time choice, but an effect of adaptive adjustment. Therefore, the interaction between economic agents in the formation and evolution of defense industrial cluster can be regarded as the game between "bounded rational people".

2.2.2 Path dependence exists in the formation and evolution of defense industrial cluster.

There are three major mechanisms in evolutionary game theory: the selection mechanism, mutation mechanism and diffusion mechanism. Defense industrial cluster can also be seen as the results of continues evolution of defense industry under the effects of the three mechanisms. Under the action of selection mechanism, individuals of low profits will be eliminated, and individuals of high returns will be able to survive.

Under the action of mutation mechanism, individuals seek new resources through various channels to achieve rapid development. New combination forms of military and civilian resources appear continuously, thus leading to new defense industrial clusters. Diffusion mechanism is mainly included in the following: external individuals engage in industrial cluster and survive through the selection mechanism. Other individuals will choose a similar way. This way of cluster will be gradually developed and evolved into the norm of economic system. Under the action of three mechanisms above, path dependence exists in the evolution of defense industrial cluster.

This means that the formation and evolution of defense industrial cluster depends largely on the initial state of defense industry. Initial state, the more conducive to the individuals engaging in industrial clusters, the more individuals will participate, the clustering will develop faster.

Path dependence is a double-edged sword. In certain condition, it can provide technical knowledge and system guarantee to reduce the uncertainty and support the formation and evolution of defense industrial cluster. But it also may become the obstacles and bottlenecks of restricting the development of cluster.

2.2.3 The result of defense industrial cluster evolution have multiple equilibrium

Due to the path dependence in defense industrial cluster formation and evolution, the initial state of system will have significant influence on the result. Nuances in initial state could make the defense industrial cluster on a different evolution path, thus appeared completely different evolution results. That means the defense industrial cluster evolution will eventually tend to a steady state, however, the steady state is not the only one, but multiple. In fact, in addition to individuals' preference and the influence of the initial conditions, the equilibrium results of game and the degree of defense industrial cluster development are also affected by also by macro policy and a set of external random factors. Under certain conditions, the behavior pattern of individual in evolution will tend to cooperation, cooperative equilibrium may be achieved so that further development of defense industrial cluster is insured.

When external conditions change, under the influence of path dependence, the behavior of individuals may subsequently change. In this case, a non-cooperative equilibrium results may appear.

Therefore, the main features of evolution of defense industrial cluster are consistent with the basic characteristics in evolutionary game theory. The framework of evolutionary game model can be used to construct a macro model with micro foundation. This model can be used to analyze behavior decision of "bounded rational people".

3. AN ANALYSIS OF THE FORMING AND DEVELOPING MECHANISMS FOR DEFENSE INDUSTRIAL CLUSTERS BASED ON EVOLUTIONARY GAME MODEL

The forming and developing of defense industrial clusters can be as the results of dynamic game between stakeholders such as military enterprises and civil enterprises. In this process "bounded rational" economic agents are affected by complexity and diversity in the game. Their decision-making process is a dynamic process of learning and strategy adjustment.

3.1 Basic assumption

To highlight the evolutionary characters and weaken insignificant factors, this research is based on the hypothesis as follows:

1）There are two types of economic agents, respectively is military enterprises and civil enterprises. Both of them are Individuals with bounded rationality. Their strategy sets are (cooperation, non-cooperation).

(2) Individual selects cooperative strategy will pay a certain amount of transaction costs for acquiring information and communicate with each other to facilitate collaboration. The transaction cost of military enterprise is c1. And the transaction cost of civil enterprise is c2.

(3) If both military and civil enterprises select cooperative strategies, then reaches cooperation.

The amount of capital invested in cooperative program by military enterprise is v1, and which made by civil enterprise is v2. a is the extra yield generated by cooperative program in defense industrial cluster. b is proportion of extra yield which civil enterprise obtained from cooperation, and 1-b is the proportion which made by military enterprise.

(4) If military and civilian enterprises both choose non-cooperative strategy, both of them can only get the normal returns, respectively are π_1, π_2.

(5）In the initial stage of the game, the proportion of military enterprises using cooperative strategies is $p\ (0 \le p \le 1)$, while the proportion of which using non-cooperative strategies is $1-p$. The proportion of civil enterprises using cooperative strategies is $q\ (0 \le q \le 1)$, and the proportion of which using non-cooperative strategies is $1-q$.

3.2 A dynamic evolutionary model on defense industrial cluster

Hypothesis 3 and Hypothesis 4 shows that the income of military and civilian enterprises can be divided into two parts: normal income obtained from independent operation and the additional revenue obtained from cooperative program. If military and civilian enterprises both choose non-cooperative strategy, both of them can only get the normal returns, respectively are π_1, π_2.If both of them choose cooperative strategies, the benefit of military enterprise is $\pi_1 - v_1 - c_1 + abV$ and benefit of civil enterprise is $\pi_2 - v_2 - c_2 + (1-b)aV$. If the military enterprise chooses cooperative strategy, while civilian enterprise chooses non-cooperative strategy, the benefit of military enterprise is $\pi_1 - c_1$ and benefit of civil enterprise is π_2. If civilian enterprise chooses cooperative strategy, while military enterprise chooses non-cooperative strategy, the benefit of military enterprise is π_1 and benefit of civil enterprise is $\pi_2 - c_2$.

Therefore, the expected return of military enterprises choosing cooperative strategy is

$$U_1^1 : U_1^1 = q(\pi_1 - v_1 - c_1 + abV) + (1-q)(\pi_1 - c_1) = \pi_1 - c_1 - qv_1 + abqV \quad (3)$$

The expected return of military enterprises choosing non-cooperative strategy is U_1^2:

$$U_1^2 = q(\pi_1) + (1-q)(\pi_1) = \pi_1 \quad (4)$$

In this case, the total expected profit of military enterprise is U_1:

$$U_1 = pU_1^1 + (1-p)U_1^2 = \pi_1 - pc_1 - pqv_1 + abqpV \quad (5)$$

The expected return of civil enterprises choosing cooperative strategy is U_2^1:

$$U_2^1 = p[\pi_2 - v_2 - c_2 + a(1-b)V] + (1-p)(\pi_2 - c_2) = \pi_2 - c_2 - pv_2 + apV - abpV \quad (6)$$

The expected return of civil enterprises choosing non-cooperative strategy is U_2^2:

$$U_2^2 = p(\pi_2) + (1-p)(\pi_2) = \pi_2 \quad (7)$$

In this case, the total expected profit of military enterprise is U_2:

$$U_2 = qU_2^1 + (1-q)U_2^2 = \pi_2 - qc_2 - qpv_2 + apqV - abpqV \quad (8)$$

Accordingly, we can get the replicated dynamic equations of military enterprise and civil enterprise respectively.

$$\frac{dp}{dt} = p(U_1^1 - U_1) = p(1-p)(abqV - c_1 - qv_1) \quad (9)$$

$$\frac{dq}{dt} = q(U_2^1 - U_2) = q(1-q)(apV - abpV - c_2 - pv_2] \quad (10)$$

Equation 9 is the replicated dynamic equation of military enterprise, which shows that：If the benefit of military enterprise which chooses cooperative strategy is larger than the average, the number of cooperative military enterprises will increase. If the benefit of military enterprise which chooses cooperative strategy is less than the average, the number of cooperative military enterprises will drop. Equation 10 is the replicated dynamic equation of civil enterprise, which shows similar information.

3.3 Analysis of the equilibrium results of the model

The replicated dynamic equations of military enterprises and civil enterprises reflect the dynamic process of the formation and evolution of the defense industry cluster. If we set $\frac{dp}{dt} = 0$, the roots of this equation are p=0; p=1 and $q = \frac{c_1}{abV - v_1}$. If we set $\frac{dq}{dt} = 0$， the roots of this equation are q=0; q=1 and $p = \frac{c_2}{(1-b)aV - v_2}$. Accordingly, we can get 5 equilibrium points in the game of defense industry cluster, which are O= (0，0); A= (0，1); B = (1，0); C= (1，1) and D=（$\frac{c_2}{(1-b)aV - v_2}$，$\frac{c_1}{abV - v_1}$）.

As for the civil enterprises, when $p=\frac{c_2}{(1-b)aV-v_2}$, there will always be $\frac{dq}{dt}=0$. When $p>\frac{c_2}{(1-b)aV-v_2}$, there will be $\frac{dq}{dt}=0$ only when q=0 or q=1. Before reaching an equilibrium point, there will be $\frac{dq}{dt}>0$, thus q=1 is the evolutionarily stable strategy. When $p<\frac{c_2}{(1-b)aV-v_2}$, there will be $\frac{dq}{dt}=0$ only when q=0 or q=1. Before reaching an equilibrium point, there will be $\frac{dq}{dt}<0$, so q=0 is the evolutionarily stable strategy.

Correspondingly, for military enterprises, when $q=\frac{c_1}{abV-v_1}$, there will always be $\frac{dp}{dt}=0$. When $q>\frac{c_1}{abV-v_1}$, there will be $\frac{dp}{dt}=0$ only when p=0 or p=1.

Before reaching an equilibrium point, there will be $\frac{dp}{dt}>0$, thus p=1 is the evolutionarily stable strategy. When $q<\frac{c_1}{abV-v_1}$, there will be $\frac{dp}{dt}=0$ only when p=0 or p=1. Before reaching an equilibrium point, there will be $\frac{dp}{dt}<0$, so p=0 is the evolutionarily stable strategy.

The dynamic evolution of defense industrial clusters the defense can be represented in figure 1, and there are $p^*=\frac{c_2}{(1-b)aV-v_2}$ as well as $q^*=\frac{c_1}{abV-v_1}$.

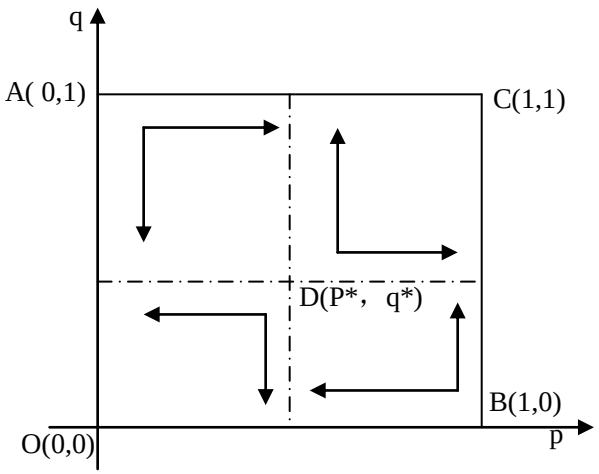

FIG 1. Dynamic evolutional model of defense industrial cluster

As can be seen from Figure 1, (1, 1) and (0, 0) are possible evolutionarily stable strategies in the evolutionary game of defense industrial cluster. Equilibrium strategy of the game mainly depends on the initial state of the system and the threshold P* and q*. When the initial state is in area OD, the system will automatically converge to (0, 0). The equilibrium strategies are non-cooperation. When the initial state is in area CD, the system will automatically converge to (1, 1).

The equilibrium strategies are cooperation. When the initial state is in area AD and DB, the direction of converge is uncertain. When the system's initial state is in the D region, small changes of the initial state will affect the final result of the evolution.

4. ANALYSIS OF THE FACTORS AFFECTING THE EVOLUTION OF DEFENSE INDUSTRIAL CLUSTER

In the development of China's defense industrial cluster, there are two long-run equilibriums: cooperation and non-cooperation. Cooperative equilibrium means civil-military integration is achieved and a new defense industrial cluster is formed.

Non-cooperative equilibrium means that the military and civilian enterprises are gathering only geographically, and have not yet formed a defense industry cluster. Equilibrium strategy of the game mainly depends on the initial state of the system and the threshold P* and q*.

And the initial state of the system is partly determined by the threshold. When the proportions of military enterprises and private enterprises who choosing cooperative strategy are less than the threshold P* and q*, the initial state will be in area OD.

When the proportions of military enterprises and private enterprises who choosing cooperative strategy are larger than the threshold P* and q*, the initial state will be in area CD.

Thus, the key factors controlling the evolution of defense industrial cluster is the value of P* and q*. The smaller P* and q* are, the greater the probability of cooperation will be.

From the expressions of P* and q*, we can see that P* and q* are mainly affected by four factors: profit of cooperation (a), distribution of cooperation profit (b), the amount of investment (v_i) and transaction cost(c_i).

4.1 The influence of cooperative profit distribution on the evolution of defense industrial cluster

Take partial derivative of P* and q* with respect to b, which is proportion of extra yield which civil enterprise obtained from cooperation, we can get $\frac{\partial p^*}{\partial b} > 0, \frac{\partial q^*}{\partial b} < 0$. The results show that the larger the proportion of the civil enterprises gains in the cooperation, more military enterprises choose not to cooperate, while more civil enterprises choose to cooperate. When the distribution of profit is more conducive to an enterprise, the enterprise will be more motivated to promote cooperation.

4.2 The influence of profit of cooperation on the evolution of defense industrial cluster

Take partial derivative of P* and q* with respect to a, which is the extra yield generated by cooperative program in defense industrial cluster, we can get $\frac{\partial p^*}{\partial a} < 0, \frac{\partial q^*}{\partial a} < 0$. When the yield increase, the value of p*, q* will decrease, the probability of forming a defense industrial cluster will increase. On the contrary, when the yield decrease, the value of p* and q* will increase, the probability of forming a defense industrial cluster will decrease. This means that the increase of expected revenue will lead to the increase of possibility of forming a defense industrial cluster.

4.3 The influence of the amount of investment on the evolution of defense industrial cluster

Take partial derivative of P* and q* with respect to v_i, which is the amount of capital invested in cooperative program by military enterprise or civil enterprise, we will get $\frac{\partial p^*}{\partial v_1} < 0, \frac{\partial q^*}{\partial v_2} < 0$.

When the amount of capital invested in cooperative program increase, the value of p*, q* will decrease, the probability of forming a defense industrial cluster will increase. On the contrary, when the amount of capital invested in cooperative program decrease, the value of p* and q* will increase, the probability of forming a defense industrial cluster will decrease.

This means that the increase of investment made by military enterprises and civil enterprises may due to the increase of possibility of cooperation.

4.4 The influence of transaction cost on the evolution of defense industrial cluster

Take partial derivative of P* and q* with respect to c_i, which is the transaction cost of military enterprises and civil enterprises , we will get $\frac{\partial p^*}{\partial c_1} > 0, \frac{\partial q^*}{\partial c_2} > 0$.

When the transaction cost decrease, the value of p^*, q^* will decrease, the probability of forming a defense industrial cluster will increase.

On the contrary, when the transaction cost increase, the value of p^* and q^* will increase, the probability of forming a defense industrial cluster will decrease. This means that the increase of transaction cost may due to the decrease of possibility of cooperation.

5. CONCLUSION

In order to analyze the behavior of military enterprises and civil enterprises in the evolution process of defense industrial cluster, this paper construct an evolutionary model for analyzing the evolution mechanism of China's defense industry cluster based on evolutionary game theory.

The results show that, in the development of China's defense industrial cluster, there are two long-run equilibriums: cooperation and non-cooperation. Cooperative equilibrium means civil-military integration is achieved and a new defense industrial cluster is formed. Non-cooperative equilibrium means that the military and civilian enterprises are gathering only geographically, and have not yet formed a defense industry cluster. Equilibrium strategy of the game mainly depends on the initial state of the system and the threshold P* and q*. And the initial state of the system is partly determined by the threshold.

On this basis, the paper analyzes the factors affecting the development of defense industrial cluster. The analysis indicates that there are four factors have significant influence on the long-term equilibriums: profit of cooperation, distribution of cooperation profit, amount of investment and transaction cost. In order to promote the forming of defense industry cluster, we need to proceed from the main factors above.

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