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# Cooperative Arrangement among Agents in the Strategic Emerging Industrial Clusters: Dynamic Cooperative Game and Collective Rationality

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The key competiveness of the strategic emerging industrial clusters is to master and own the core technology, and the basic approach to break through the key technologies and to enhance the strategic emerging industry's core competitiveness is cooperative innovation. We built a dynamic cooperation game model among innovation agents in strategic emerging industrial clusters based on two assumptions in this paper, and we pointed out the collective rationality requirements and individual rationality requirements under the cooperative innovation in cluster. And then, we made a comparative analysis on the investment strategy and the optimal value function between cooperation innovation alliance of under collective rationality and cluster agent under individual rationality, and finally we put forward the corresponding cooperation strategies.

## 1. Introduction

With the arrival of the era of big data, Global technology emerging industry is entering into an intensive period of unprecedented innovation. Innovation as the key feature of the emerging industry has become the dominant force to promote the development of national economy, and the emerging industrial clusters has become an important carrier of promoting industry upgrading and regional innovation. In recent years, the development of strategic emerging industries has got rapid progress in China, but it still didn't get rid of the development ideas which is "high-end industry, low-technology", the R&D efficiency of the core technology and the self-sufficiency of the key technology which is required by the development of new industry. The main reason is that innovation power is dispersing among enterprises, universities, scientific research institutions in the strategic emerging industry in China at present. So it needs to integrate human resources, technology, capital and other innovative elements through strengthening cooperation among agents in the strategic emerging industry to achieve the core competitiveness of industry effectively. Therefore, it has important significance to discuss the cooperation question in strategic emerging industrial clusters.

The cooperation question concerning about the strategic emerging industry cluster has got some achievements, and the research focused mainly on cooperation power, cooperation mode, cooperation alliance, cooperation innovation strategy and stability. The main representative scholars as follows: Shen Junxi (2012) hold that innovating the organizational model of the cooperation among enterprises, universities and research institutions is the basic path to surmounting the core technology and enhance the core competitiveness of strategic emerging industry in the current. Yang Yiwen, Zheng Jianghuai and Ren Zhicheng (2012) analyzed the influence of establishing cooperation model among enterprises, universities and research institutions of R&D team and cooperation model of R&D company on the innovation level in the case of the feasibility of the supervision through constructing quantity model.Ma Liang, Zhang Qinghui (2013) considered that Cooperative R&D is the most appropriate form of organization development owning to the features such as prospective, risk, complexity of the strategic emerging industry. Li Juanjuan (2013) discussed the factors affecting research alliance innovation during the development of the strategic emerging industry, and then pointed out the governance mechanism of the research alliance innovation. Li Yuhua, Wu Xiaofeng, Hu Yaoying (2013) considered that the expected benefits of collaborative innovation, collaborative innovation risk and collaborative innovation knowledge were important factors of collaborative innovation in the strategic

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emerging industrial clusters. Zhou Shaodong, Wang Changsheng (2014) established a cooperative game model based on Shapley value and proposed a method of selecting technical route of the strategic emerging industry. Li Yuhua, Wu Xiaofeng, Hu Yaoying (2014) established the collaborative innovation model between enterprises and research institutions in the innovation eco-system by using Logistic equation on the basis of analyzing the main relationship and the operating mode of the innovation eco-system of the strategic emerging industry.

In summary, there are some scholars using the game model to discuss the cooperation game issues in the strategic emerging industry, but it is still lack of concern on interests' distribution among various cooperation actors in the industrial cluster. Meanwhile, according to the hypothesis of economic man of economics, the conduct code of people in the game is individual rationality rather than collective rationality under normal circumstances. Therefore, the approach to solve the conflict between individual rationality and collective rationality is to design a mechanism to arrive collective rationality under the individual rationality rather than denying individual rationality. So it needs to consider the rational conditions of the participants in the study of the distribution of cooperation benefits. In view of the above consideration, we mainly analyzed the question on the cooperative arrangement among multiple agents in the strategic emerging industry clusters, and discussed the requirements of collective rationality and individual rationality during the process of collaborative innovation in order to guarantee reasonable distribution of cooperation income and to promote cooperation innovation successfully.

## 2. Dynamic cooperation game model

Before giving the dynamic cooperation game model among multiple agents in the industrial clusters, we present the following two assumptions:

**Assumption 1**: Every company participating the cooperation innovation in the industrial Clusters is willing to allocate their payments according to the principle of an optimal consensus which all parties have agreed initially.

In the process of cooperation innovation in the industrial clusters, every company participating cooperation is rational, it will not get involved into the cooperation alliance if the reward required through cooperation can't satisfied their individual rationality, and then, the cooperation will not be happened. Therefore, they are willing to participate together only in the case of each agrees the allocation method of cooperation payment used by alliance in the early stage of cooperation. In addition, they will try to be loyal to the alliance in the process of cooperation when they agreed the allocation of their payments according to the principle of an optimal consensus which they have agreed initially, because it is also related to their own interests. And the principle of optional consensus specified how to cooperate and how to distribute the income among cooperative enterprises.

**Assumption 2**: The payment can be transferred in the process of cooperative innovation in the industrial clusters.

In the process of innovation cooperation, each will receive an instantaneous reward at each time, therefore, each can not only compared themselves' reward at different points, but also can compared the reward of different enterprises if the payment can be transferred, so it can increase their confidence to the cooperative alliance.

According to Professor Yang Rongji and Petrossian's research, a dynamic cooperation innovation model which consists of enterprises whose amount is n in the industrial clusters was built in this paper. Supposed that the start time and the end time of the game is $t_0$ and $T$, and the initial state of the game is $x_0$, the state space of the game is $X \in R^m$, $x(t)$ represents the state variable, which allows the state of the track is $\{x(t), t_0 \le t \le T\}$ and $x_i(t) \in X_i \in R^m$ represents the state variable of company i at the point time of t, and this state variable is changing with time. $s_i \in S$ represents the control of company i, because it represents a strategic approach to progress along with time, while $s_i(t)$ indicates the control of enterprise at the time of t.

In addition, according to the assumption 2, given a discount rate $r(t)$. For $t \in [t_0, T]$, the reward of every enterprise participating the cooperation innovation at the time t after the time $t_0$ will need to be discounted according to the discount factor $\exp[-\int_{t_0}^{t} r(\theta)d\theta]$. At the time of t, assuming that the enterprise i will receive instant reward $f^i[t, x_i(t), s_i(t)]$ from the investment profit, profit and tax, and at the end time of T, assumed that company i will get the final reward $p^i(x_i(T))$ which represents the present value of the future potential net income calculated according to the various aspects of the situation and the economic potential of the company at the end time of T. Finally, we use $x_N(t) = [x_1(t), x_2(t), \cdots, x_n(t)]$ indicates the state variables of all enterprises at the time of t and use $x_N^0 = [x_1^0, x_2^0, \cdots, x_n^0]$ indicates the initial state of all enterprises.

Based on the above analysis, we can conclude that every enterprise's reward includes two aspects: one is instant reward obtained by each at the time of t; anther is the end reward received at the end of innovation, that is:

$$R_i[x_i(t), s_i(t)] = \int_{t_0}^{T} f^i[t, x_i(t), s_i(t)] \exp[-\int_{t_0}^{t} r(\theta)d\theta]dt + p^i(x_i(T)) \exp[-\int_{t_0}^{T} r(\theta)d\theta]$$

$$f^i(\bullet) \geq 0, p^i(\bullet) \geq 0 \quad i \in [1,2,\cdots n] \tag{1}$$

And the change of the dynamic game status depends on:

$$\frac{dx_i}{dt} = g^i[t, x_i(t), s_i(t)], x_i(t_0) = x_i^0, i \in [1,2,\cdots,n] \tag{2}$$

In such a dynamic cooperative innovation game, we should not only guarantee the collective rationally of the cooperation alliance, but also should meet the individual rationality of every enterprise in the cooperation alliance if we want to make the cooperation to be successful. Collective rationality required that cooperation strategies formulated by participants can lead to the state of Pareto optimal, and individual rationality required that the individual rational of participants must be maintained along the optimal trajectory of the game all the time,

### 3. Analysis of cooperative arrangements among multiple agents

Here, we consider a case of technical innovation in the industrial clusters which consists of three enterprises. Assumed that the start time for the improvement of technology is $t_0$, and the end time is T. We use $x_i(t) \in X_i \in R^m$ represents technical level of enterprise i at the time of t, $s_i(t)$ represents the capital invested on the improvement of technology by enterprise i at the time of t. The instant reward of every enterprise i at the time of t, is $a_i[x_i(t)^{1/2}] - c_i s_i(t)$ [14], which $a_i, c_i$ are normal numbers, and $a_i[x_i(t)]^{1/2}$ represents the net operating revenue of the enterprise i with the technical level is $x_i(t)$, and $c_i s_i(t)$ represents the investment costs of enterprise i. According to the previous analysis, all the reward of company i received is the sum of the discounted value of the instant reward and the end reward in the time zone of $[t_0, T]$. Therefore, the present value of every enterprise received in the time zone of $[t_0, T]$ can be expressed as follows whether the enterprise participating the cooperation:

$$\int_{t_0}^{T} [a_i x_i(t)^{1/2} - c_i s_i(t)] e^{-r(t-t_0)} dt + p_i[x_i(T)]^{1/2} e^{-r(T-t_0)}, i \in N = \{1,2,3\} \tag{3}$$

Among them, $p_i$ is also normal number, $p_i[x_i(T)]$ represents the residual value of the technology of enterprise i at the time of T. Dynamic changes of technology level $x_i(t)$ of enterprise i can be expressed as follows:

$$\frac{dx_i(t)}{dt} = \beta_i[s_i(t)x_i(t)]^{1/2} - \sigma x_i(t) \tag{4}$$

Among them, $\beta_i$ represents the improvement of technology when investing the capital $s_i(t)$, and $\sigma$ can be abstracted as the depreciation rate of technology.

**(1) Meeting conditions of collective rationality**

Since the enterprises in the industrial cluster can produce a synergistic effect, therefore, the dynamic system $x_i(t)$ of the changing of technology level of enterprise i can be expressed as:

$$\frac{dx_i(t)}{dt} = [\beta_i[s_i(t)x_i(t)]^{1/2} + \lambda_j^{[j,i]}[x_j(t)x_i(t)]^{1/2} + \lambda_l^{[l,i]}[x_l(t)x_i(t)]^{1/2} - \sigma x_i(t)] \tag{5}$$

Among them, $x_i(t_0) = x_i^0 \in X_i$, $i, j, l \in N = \{1,2,3\}$ and $i \neq j \neq l$, $\lambda_j^{[j,i]}[x_j(t), x_i(t)]^{1/2}$ presents the positive impact of enterprise $i$ on the progress level of enterprise $j$ under the synergies among enterprises, at the same time, $\lambda_l^{[j,i]}[x_l(t), x_i(t)]^{1/2}$ presents the positive impact of enterprise $j$ on the progress level of enterprise $i$ under the synergies among enterprises. Therefore, the overall revenue of the three companies is equal to the cooperation revenue of the three enterprises:

$$\int_{t_0}^{T} \sum_{i=1}^{3} [a_i x_i(t)^{1/2} - c_i s_i(t)] e^{-r(t-t_0)} dt + \sum_{i=1}^{3} p_i[x_i(T)]^{1/2} e^{-r(T-t_0)} \tag{6}$$

And the dynamic system is the same to formula (5).

According to theorem 1 of Yang Rongji and Petrossian's research:
If the optimal control set of $\left\{s_{K_2}^{*}(t,x_{K_2}(t))=\phi_{K_2}^{(t_0)*}(t,x_{K_2}(t))\right\}$, and $\phi_{K_2}^{(t_0)*}(t,x_{K_2}(t))=[\phi_1^{(t_0)*}(t,x_1(t)),\phi_2^{(t_0)*}(t,x_2(t)),\cdots,\phi_{k_2}^{(t_0)*}(t,x_{k_2}(t))]$ is the optimal solution for the model (3), there is a continuous differentiable function $V^{(t_0)}(t,x(t))$ satisfies the following Bellman equation only in the interval of $[t_0,T]$:

$$-V_t^{(t_0)}(t,x(t))=\max\{\sum_{i=1}^{K_2} f^i[t,x_i(t),s_i(t)]\exp[-\int_{t_0}^{t} r(\theta)d\theta] + V_x^{(t_0)}\sum_{i=1}^{K_2} g^i[t,x_i(t),s_i(t)]\}$$

Satisfy the following boundary conditions:

$$V^{(t_0)}(T,x(T))=\sum_{i=1}^{K_2} p^i(x_i(T))\exp[-\int_{t_0}^{T} r(\theta)d\theta]$$

Among them, $V^{(t_0)}(t,x(t))$ represents the value function of the whole in the interval of $[t,T]$.
And we can get the following Bellman equation:

$$\begin{aligned}-V_t^{(t_0)}(t,x(t))=\max\{&\sum_{i=1}^{3}[a_i(x_i(t))^{1/2}-c_i s_i(t)e^{-r(t-t_0)}]\\&+\sum_{i=1}^{3}V_{x_i}^{(t_0)}[\beta_i(s_i(t)x_i(t))^{1/2}+\lambda_j^{[j,i]}(x_j(t)x_i(t))\\&+\lambda_l^{[l,i]}(x_l(t)x_i(t)-\sigma x_i(t))]\}\end{aligned} \tag{7}$$

Satisfy the following boundary conditions:

$$V^{(t_0)}(T,x(T))=\sum_{i=1}^{3} p_i(x_i(T))^{1/2}e^{-r(T-t_0)} \tag{8}$$

According to the principle of maximizing [15-17], we can get the following formula (9) after maximizing the formula (6):

$$s_i(t)=\frac{\beta_i^{\,2}}{4(c_i)^2}[V_{x_i}^{(t_0)i}(t,x_i)e^{r(t-t_0)}]^2 x_i \tag{9}$$

According to the formula (7), formula (8), and formula (9), we can obtain:

$$\begin{aligned}&-V_t^{(t_0)}(t,x(t))=\sum_{i=1}^{3}a_i x_i^{1/2}e^{-r(t-t_0)}-\frac{\beta_i^2}{4c_i}[V_{x_i}^{(t_0)i}(t,x_i)]^2 e^{-r(t-t_0)}x_i\\&+\sum_{i=1}^{3}\left\{\frac{\beta_i^2}{2c_i}[V_{x_i}^{(t_0)i}(t,x_i)]^2 e^{-r(t-t_0)}x_i+V_{x_i}^{(t_0)i}(t,x_i)[\lambda_j^{[j,i]}(x_j,x_i)+\lambda_l^{[l,i]}(x_l,x_i)-\sigma x_i]\right\}\end{aligned} \tag{10}$$

By solving the formula (10), we can get:

$$V_t^{(t_0)}(t,x(t))=[y_1(t)x_1^{1/2}+y_2(t)x_2^{1/2}+y_3(t)x_3^{1/2}+z(t)]e^{-r(t-t_0)} \tag{11}$$

Among them:

$$\frac{dy_i}{dt}=(r+\frac{\sigma}{2})y_i(t)-\frac{\lambda_i^{[i,j]}}{2}y_j(t)-\frac{\lambda_i^{[i,l]}}{2}y_l(t)-a_i \quad \frac{dz(t)}{dt}=rz(t)-\sum_{i=1}^{3}\frac{\beta_i^2}{16c_i}[y_i(t)]^2$$

Therefore, according to the requirements of collective rationality, the formula (11) is the optimal value function of dynamic cooperation alliance among enterprises in the cluster innovation networks.

**(2) Meeting conditions of individual rationality**

The enterprise will received the value function shown in the model (3) and models (4) when it is alone to innovate and for model (3) and models (4), and we solved the model (3) and models (4) according to the Theorem 2 in literature Yang Rongji and Petrossian's research: The optimal policy set of $s_{K_1}^{(t_0)*}(t,x_i(t))=\delta_{K_1}^{(t_0)*}(t,x_i(t))$, and $\delta_{K_1}^{(t_0)*}(t,x_{K_1}(t))=[\delta_1^{(t_0)*}(t,x_1(t)),\delta_2^{(t_0)*}(t,x_2(t)),\cdots,\delta_{k_1}^{(t_0)*}(t,x_{k_1}(t))]$ is a feedback Nash equilibrium solution for the non cooperative game, there is a continuous integral function $U^{(t_0)i}(t,x_i(t))$ to meet the following equations only in the interval of $[t_0,T]$:

$$-U_t^{(t_0)i}(t,x_i(t))=\max\{f^i[t,x_i(t),s_i(t),\delta_j^{(t_0)*}(t,x_j(t))]\exp[-\int_{t_0}^{t} r(\theta)d\theta] + U_x^{(t_0)i}g^i[t,x_i(t),s_i(t),\delta_j^{(t_0)*}(t,x_j(t))]\}$$

Satisfy the following boundary conditions:

$$U^{(t_0)i}(T,x(T))=p^i(x_i(T))\exp[-\int_{t_0}^{T} r(\theta)d\theta]$$

Among them, $i\in K_1, j\in N\setminus K_1$, $U^{(t_0)i}(t,x_i(t))$ represents the value function of the enterprise $i$ in the interval of $[t,T]$.
So we can get the following Bellman equation:

$$-U_t^{(t_0)i}(t,x_i(t)) = \max\{[a_i x_i(t)^{1/2} - c_i s_i(t)]e^{-r(t-t_0)} + U_x^{(t_0)i}[\beta_i(s_i(t)x_i(t))^{1/2} - \sigma x_i(t)]\} \quad (12)$$

Satisfy the following boundary conditions:
$U^{(t_0)i}(T,x(T)) = p_i(x_i(T))^{1/2}e^{-r(T-t_0)}$

According to the principle of maximizing [15-17], we can get the following formula (13) after maximizing the formula (12):

$$s_i(t) = \frac{\beta_i^2}{4(c_i)^2}[U_{x_i}^{(t_0)i}(t,x_i)e^{r(t-t_0)}]^2 x_i \quad (13)$$

According to the formula (11), formula (12), and formula (13), we can obtain:

$$-U_t^{(t_0)i}(t,x(t)) = a_i x_i^{1/2}e^{-r(t-t_0)} - \frac{\beta_i^2}{4c_i}[U_{x_i}^{(t_0)i}(t,x_i)]^2 e^{-r(t-t_0)}x_i + \frac{\beta_i^2}{2c_i}[U_{x_i}^{(t_0)i}(t,x_i)]^2 e^{-r(t-t_0)}x_i - \sigma U_{x_i}^{(t_0)i}(t,x_i)x_i \quad (14)$$

By solving the formula (14), we can get:
$U_i^{(t_0)}(t,x_i(t)) = [y_i(t)x_i^{1/2} + z_i(t)]e^{-r(t-t_0)}$ (15)

Among them, $\frac{dy_i}{dt} = (r+\frac{\sigma}{2})y_i(t) - a_i$, $\frac{dz_i}{dt} = rz_i(t) - \frac{\beta_i^2}{16c_i}[y_i(t)]^2$

According to the requirement of individual rationality, it should meet the condition as follows: $\eta^i(x_N^0, T-t_0) \geq \delta^i(x_N^0, T-t_0), i \in \{1,2,\cdots,n\}$ and

$$\sum_{K_2 \in N}\frac{(k_2-1)!(n-k_2)!}{n!}[V^{(t_0)K_2}(x_{K_2}^0, T-t_0) - V^{(t_0)K_2\setminus i}(x_{K_2\setminus i}^{t_0}, T-t_0)] \geq [y_i(t)x_i^{1/2} + z_i(t)]e^{-r(t-t_0)}$$

Among them, $V^{(t_0)K_2}(x_{K_2}^0, T-t_0)$ and $V^{(t_0)K_2\setminus i}(x_{K_2\setminus i}^0, T-t_0)$ can be calculated according to the formula (11).

Therefore, it satisfies the individual rationality of the innovation agents in the industrial cluster as long as the above conditions are satisfied.

## 4. The strategy of promoting cooperative innovation

In the strategic emerging industry clusters, though it is a partnership among enterprises, the enterprises are more concerned about their own interests, at the same time, the cooperation among enterprises is subject to influenced by many factors, such as opportunism, adverse selection and other factors during the process of cooperation, and these factors will lead to the instability of cooperation among enterprises in the industrial clusters. Therefore, in order to ensure the cooperation among enterprises successfully, the following suggestions are put forward:

(1) Coordinating the cooperation relations between the various actors actively in the industrial clusters

Firstly, strengthening the construction of the intermediary organizations in the industrial clusters. The comparative innovation among various agents depends on the service of the intermediary organizations. on the one hand, the introduction and training of various talents, as well as the R&D of product and other aspects are not separated from the agency's advisory services; on the other hand, the production of scientific and technological products generated by the cooperative innovation needs the intermediary organizations helping to spread to the market, therefore, we should fully rely on the network resources such as local government, universities, research institutions and others to establish and maintain the various types of intermediary organizations. Secondly, we should promote the transfer of achievement through formulating effective measures on technology development and technology protection. On the one hand, establishing the relevant policies and regulations for the technical innovation of the main actors in the industrial clusters by strengthening the relevant legislation to rectify and standardize the market economic order. On the other hand, enhancing the awareness of IPR protection through propagating the related policies and regulations of local governments vigorously.

(2) Improving the management system and regulations of cooperation in the industrial clusters

On the one hand, we should continue to attracting universities or research institutions or outstanding high-tech industries to the industrial clusters to promote the flowing of resource such as advanced technologies, information and other factors. On the other hand, we should introduce negative entropy outside to the cluster constantly to offset the positive entropy in the industrial clusters, and then providing a favorable external environment for cooperation among various agents. Meanwhile, we should develop and strengthen the relevant laws and regulations for cooperation among various agents in the industrial clusters to make the cooperation among agents have laws to abide. In addition, we should develop and use a variety of preferential

policies to guide and encourage cooperation to enhance the competitiveness in the process of cooperation among various agents in the industrial clusters.

(3) Building the "CIS" innovation network in the industrial clusters

That is to strengthen the integration of resources, and establishing the "CIS" innovation network which is consist of companies, universities, research institutions, associations and advisory organizations. In order to achieve the sustainable development of the industrial clusters, we should improve the innovation ability, especially using the supporting role of cluster network to innovation to foster the innovation networks, encourage collective learning in the industrial clusters, and enhance the overall innovation capability, and then, forming a good cooperation innovation network which is consist of government departments, enterprises, universities and research institutes, intermediary institutions and so on. And we should establish "CIS ' board of directors by the agents in the industrial clusters to enhance economies of scale of public inputs significantly.

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