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The Cultivation Strategy of High-level Engineering Management Talents in New Energy Industries

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Abstract—It is necessary and urgent to study the cultivation strategy of high-level engineering management talents who are served as leading forces of new energy industries. Based on the bounded rational hypothesis, this study constructed an evolutionary game model between higher institutions and new energy industries on the cultivation of high-level engineering management talents, theoretically analyzed their evolutionary stable strategies, and numerically verified the evolutionary stability of their strategies. The findings show that there are two evolutionary stable strategies for higher institutions and new energy industries: (synergistic innovation, synergistic innovation), (conventional cooperation, conventional cooperation). The probability of converging on (synergistic innovation, synergistic innovation) is negatively related to synergistic innovation cost and the benefit from opportunism, positively related to synergistic innovation benefit. Furthermore, the rate of convergence of the strategies for achieving the result of (synergistic innovation, synergistic innovation) will increase when there is a smaller probabilistic distance between the initial strategy and "synergistic innovation" strategy. Finally, suggestions are proposed for the synergistic innovation of talents cultivation between new energy industries and higher institutions.

Keywords—talents cultivation, new energy industry, synergistic innovation, evolutionary game, numerical simulation

I. INTRODUCTION

In order to mitigate the negative effects caused by climate change, Chinese government has regarded low-carbon economy transition as an important task. The development of new energy industries becomes an inevitable choice for the acceleration of low-carbon economy transition. In order to support the research, development and application of new energy industries, some higher institutions have introduced new energy majors approved by the ministry of education, such as the nuclear science and technology, water resources and hydropower engineering, and resource recycling science and engineering. Although these institutions have supplied a large number of talents for new energy industries, there still exists the shortage of talents at different levels. The development of new energy industries necessarily depend on the support of high-level engineering management talents, especially those with strong innovation and research ability, therefore, it is very important and necessary for the cooperation of talents cultivation between new energy industries and higher institutions.

Existing studies on the combination of industrial development and the postgraduate education of engineering management have mainly focused on the following two aspects. The first stream highlighted the long-term mechanism, and aimed to set up a complete industry-university-research cooperation[1–3]. The second line believed that high-level engineering management education contributed to the speed up of the adaption to the requirement of macroscopic industrial structure adjustment, which can provide strong intellectual support for industrial development[4]. In fact, the docking problem of new energy industrial development and postgraduate education of engineering management have been investigated by some researchers, and some problems arise for new energy industries, for example, the evaluation of new energy resources is unscientific, the testing and certification system of new energy products is imperfect, management talents cannot adapt to the rapid development of the market, technical conversion rate is low, and so on, thus there hasn't formed a postgraduate education system of engineering management to support the application of new energy industries. With the unceasing expansion of new energy industry scale, industrial development is facing a dilemma of insufficient strength because of the lack of core technologies and high-level engineering management talents who have the ability to make systematic analysis. In fact, the successful development and application of new energy mainly depends on the support of technology and high-level engineering management talents, therefore, it is necessary to accelerate the establishment of new energy development and utilization as the core technology system, and strengthen the cultivation of high-level engineering management talents with taking into account the current resource endowment in China, which will contribute to the transition of low-carbon economy and the occupation of the commanding height on future competition of international science and technology and economy. This study will contribute to the rapid development of new energy industries by improving the postgraduate education of engineering management, as well as the reform and innovation of higher education arriving from the promotion effect of the development of new energy industries.

II. ANALYSIS FOR THE EVOLUTIONARY GAME MODEL

A. Assumptions of the Evolutionary Game Model

The cultivation of high-level engineering management talents generally involves higher institutions and new energy industries, and they are bounded rational players because they have to make a decision based on incomplete and asymmetric information. Furthermore, the higher institutions are considered to have two optional strategies: "synergistic innovation" (U_1) and "conventional cooperation" (U_2), new energy industries are also considered to have two optional strategies: "synergistic innovation" (E_1) and "conventional

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cooperation" (E_2). Synergistic innovation represents high-level engineering management talents are synergistically cultivated by both sides to adapt to the development of new energy industries, and conventional cooperation indicates that at least one side has the possibility to perform opportunistic behavior. Furthermore, there are four combinations of the strategies of higher institutions and new energy industries. Based on the parameters in Table I, and the payoff matrix for the game is shown in Table II.

B. Constructions of the Replicator Dynamic Equations

Based on evolutionary game theory, the replicator dynamic equation proposed by Taylor and Jonker represents the dynamic differential equation for the frequency of one strategy adopted by one population[5–6]. In the initial stage, let x $(0 \leq x \leq 1)$ be the proportion of higher institutions following "synergistic innovation" strategy, $1-x$ is the proportion of following "conventional cooperation" strategy, y $(0 \leq y \leq 1)$ be the proportion of new energy industries following "synergistic innovation" strategy, and $1-y$ is the proportion of following "conventional cooperation" strategy.

(1) Replicator dynamic equation for higher institutions' strategies

The expected payoffs for "synergistic innovation" strategy and "conventional cooperation" strategy played by higher institutions are represented by E_{11} and E_{12}, and the average expected payoff is represented by E_1. Hence,

$$E_{11} = y(R_1 + SR_1 - C_1) + (1-y)(R_1 - C_1) \tag{1}$$

$$E_{12} = y(R_1 + OR_1) + (1-y)(R_1) \tag{2}$$

$$E_1 = xE_{11} + (1-x)E_{12} = xy \times (SR_1 - OR_1) - x \times C_1 + y \times OR_1 + R_1 \tag{3}$$

The replicator dynamic equation for higher institutions' strategies is established as follows:

$$F(x) = \frac{dx}{dt} = x(E_{11} - E_1) = x(1-x) \times [y \times (SR_1 - OR_1) - C_1] \tag{4}$$

(2) Replicator dynamic equation for new energy industries' strategies

The expected payoffs for "synergistic innovation" strategy and "conventional cooperation" strategy played by new energy industries are represented by E_{21} and E_{22}, and the average expected payoff is represented by E_2. Analogously, the replicator dynamic equation for new energy industries' strategies is established as follows:

$$F(y) = \frac{dy}{dt} = y(E_{21} - E_2) = y(1-y) \times [x \times (SR_2 - OR_2) - C_2] \tag{5}$$

TABLE I. SUMMARY OF PARAMETERS IN THE GAME MODEL

Symbol	Meaning
R_n	Basic benefit ($n = 1, 2$), R_1 and R_2 represent the benefits acquired by higher institutions and new energy industries, respectively, when both sides follow the "conventional cooperation" strategy.
SR_n	Synergistic innovation benefit ($n = 1, 2$), SR_1 and SR_2 represent the benefits acquired by higher institutions and new energy industries, respectively, when both sides follow the "synergistic innovation" strategy.
C_n	Synergistic innovation cost ($n = 1, 2$), C_1 and C_2 represent the cost paid by higher institutions and new energy industries, when both sides follow the "synergistic innovation" strategy.
OR_n	Benefit from opportunism ($n = 1, 2$), OR_1 represents the benefit acquired by higher institutions when new energy industries follow the "synergistic innovation" strategy and higher institutions follow the "conventional cooperation" strategy, and OR_2 represents the benefit acquired by new energy industries when higher institutions follow the "synergistic innovation" strategy and new energy industries follow the "conventional cooperation" strategy.

[a] Note: There exists $C_1 < SR_1$, $C_2 < SR_2$, $OR_1 < SR_1$, $OR_2 < SR_2$, $SR_1 - C_1 > OR_1$, $SR_2 - C_2 > OR_2$ as the cultivation with synergistic innovation of high-level engineering management talents is characterized by high cost and high benefit.

TABLE II. PAYOFF MATRIX FOR THE EVOLUTIONARY GAME

Strategy combinations	Payoff for higher institutions	Payoff for new energy industries
(U_1, E_1)	$R_1 + SR_1 - C_1$	$R_2 + SR_2 - C_2$
(U_1, E_2)	$R_1 - C_1$	$R_2 + OR_2$
(U_2, E_1)	$R_1 + OR_1$	$R_2 - C_2$
(U_2, E_2)	R_1	R_2

C. Stability Analysis for the Evolutionary Game Model

TABLE III. EVOLUTIONARY STABILITY ANALYSIS FOR THEIR STRATEGIES

Equilibrium point	$Det(J)$	Sign	$Tr(J)$	Sign	Result
$A(0,0)$	C_1C_2	+	$-C_1 - C_2$	−	ESS
$B(1,0)$	$C_1(SR_2 - OR_2 - C_2)$	+	$C_1 + SR_2 - OR_2 - C_2$	+	Unstable point
$C(0,1)$	$C_2(SR_1 - OR_1 - C_1)$	+	$C_2 + SR_1 - OR_1 - C_1$	+	Unstable point
$D(1,1)$	$(SR_1 - OR_1 - C_1)(SR_2 - OR_2 - C_2)$	+	$-SR_1 + OR_1 + C_1 - SR_2 + OR_2 + C_2$	−	ESS
$E(x_0, y_0)$	$-\frac{C_1C_2(SR_1 - OR_1 - C_1)(SR_2 - OR_2 - C_2)}{(SR_1 - OR_1)(SR_2 - OR_2)}$	−	0	0	Saddle point

Based on the above analysis, let $F(x) = 0$, then $x = 0$ or $x = 1$, $y_0 = \frac{C_1}{(SR_1 - OR_1)}$; let $F(y) = 0$, then $y = 0$ or $y = 1$, $x_0 = \frac{C_2}{(SR_2 - OR_2)}$. It can be found that there are five equilibrium points comprising: $A(0,0)$, $B(1,0)$, $C(0,1)$, $D(1,1)$, and

$E\left(\frac{C_2}{(SR_2-OR_2)},\frac{C_1}{(SR_1-OR_1)}\right)$. The stability of these equilibrium points can be analyzed based on the local stability of Jacobian matrix[7], and the determinants of the Jacobian matrix can be expressed as $Det(J)=\frac{\partial F(x)}{\partial x}\times\frac{\partial F(y)}{\partial y}-\frac{\partial F(x)}{\partial y}\times\frac{\partial F(y)}{\partial x}$, and the trace of the Jacobian matrix can be expressed as $Tr(J)=\frac{\partial F(x)}{\partial x}+\frac{\partial F(y)}{\partial y}$. The equilibrium point can only be the local asymptotically stable point in a discrete system in the case when $Det(J)>0$ and $Tr(J)<0$, where the corresponding strategy is the EES. Therefore, the equilibrium points given above were substituted into the expressions for $Det(J)$ and $Tr(J)$, and the following findings were found and shown in Table III.

A phase diagram for the evolutionary process (Fig. 1) is drawn based on the results of the evolutionary stability analysis. It can be found that both $A(0,0)$ and $D(1,1)$ are the ESSs. Furthermore, both higher institutions and new energy industries will play "synergistic innovation" strategy when their initial strategies are located in the area I and II, and they will play "conventional cooperation" strategy when their initial strategies are located in the area III and IV.

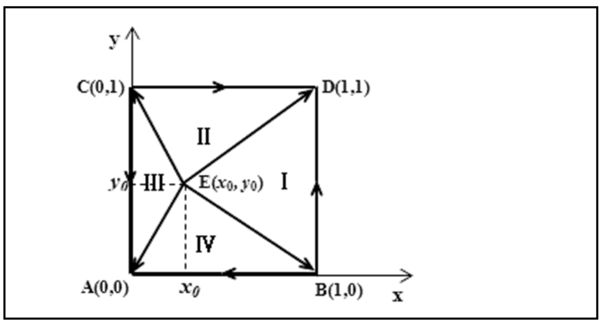


Fig. 1. Phase diagram of the evolutionary process

III. Analysis of the Factors Influencing Synergistic Innovation

It should be notable that the probability of playing "synergistic innovation" strategy will be more than the probability of playing "conventional cooperation" strategy when $S_{\mathrm{I+II}}>S_{\mathrm{III+IV}}$. Based on the above phase diagram, it can be found that $S_{\mathrm{I+II}}=1-\frac{1}{2}\left[\frac{C_2}{(SR_2-OR_2)}+\frac{C_1}{(SR_1-OR_1)}\right]$. It is necessary to analyze the influencing factors of $S_{\mathrm{I+II}}$ to further conclude the factors affecting the cultivation of high-level engineering management talents, so parameters including C_1, C_2, SR_1, SR_2, OR_1, and OR_2 were discussed in the following.

(1) From the perspective of synergistic innovation cost (i.e., C_1 and C_2). It can be analyzed that $\frac{\partial S_{\mathrm{I+II}}}{\partial C_1}=-\frac{1}{2(SR_1-OR_1)}<0$, thus $S_{\mathrm{I+II}}$ will be smaller with the increasing of the synergistic innovation cost paid by higher institutions (C_1). Analogously, $\frac{\partial S_{\mathrm{I+II}}}{\partial C_2}=\frac{1}{2(SR_2-OR_2)}<0$, thus $S_{\mathrm{I+II}}$ will be smaller with the increasing of the synergistic innovation cost paid by new energy industries (C_2). Hence, the probability of synergistically cultivating high-level engineering management talents will be lower with the increasing of the synergistic innovation cost. In general, the synergistic innovation cost can be the expenses of purchasing experimental facilities and materials, the expenses of building plants, consultation fees, service fees, conference fees. Although the probability of converging on (synergistic innovation, synergistic innovation) is negatively related to synergistic innovation cost, there are some potential benefits such as enhanced knowledge, improved technology, and increased talents. It is notable that the synergistic innovation cost should not be as low as possible, and the key is the match of cost and collaborative innovation activities, as well as the efficiency of cost control.

(2) From the perspective of synergistic innovation benefit (i.e., SR_1 and SR_2). It can be found that $\frac{\partial S_{\mathrm{I+II}}}{\partial SR_1}=\frac{C_1}{2(SR_1-OR_1)^2}>0$ and $\frac{\partial S_{\mathrm{I+II}}}{\partial SR_2}=\frac{C_2}{2(SR_2-OR_2)^2}>0$, and then $S_{\mathrm{I+II}}$ will be larger with the increasing of the synergistic innovation benefit acquired by higher institutions (SR_1) and the synergistic innovation benefit acquired by new energy industries (SR_2), thus the probability of synergistically cultivating high-level engineering management talents will be higher with the increasing of the synergistic innovation benefit. Hence, there is a positive effect of the synergistic innovation benefit on the formation of (synergistic innovation, synergistic innovation).

(3) From the perspective of benefit from opportunism (i.e.,OR_1 and OR_2). Obviously, $\frac{\partial S_{\mathrm{I+II}}}{\partial OR_1}=-\frac{C_1}{2(SR_1-OR_1)^2}<0$ and $\frac{\partial S_{\mathrm{I+II}}}{\partial OR_2}=-\frac{C_2}{2(SR_2-OR_2)^2}<0$, and then $S_{\mathrm{I+II}}$ will become smaller with the increasing of the benefit from opportunism acquired by higher institutions (OR_1) and the benefit from opportunism acquired by new energy industries (OR_2). Therefore, the probability of synergistically cultivating high-level engineering management talents will be lower with the increasing of the benefit from opportunism. In fact, one side is likely to acquire benefit by insincere cooperation because of information asymmetry and uncertain environment. Hence, higher institutions and new energy industries should take a long-term view, and sincerely cooperate with each other to synergistically cultivate high-level engineering management talents.

IV. Numerical Simulation

To visually verify the evolutionary stability of their strategies, MATLAB R2012a was used to simulate the dynamic evolutionary process and to analyze the effects of variations in the parameters on the evolutionary results. First, each parameter was assigned a value: $SR_1=10$, $OR_1=2$, $C_1=5$, $SR_2=12$, $OR_2=8$, $C_2=2$. Then the replicator dynamic equations of higher institutions and new energy industries can be obtained as follows: $F(x)=x(1-x)\times[8y-5]$, $F(y)=y(1-y)\times[4x-2]$. Therefore, it can be found that $x_0=1/2$ and $y_0=5/7$.

The dynamic evolutionary paths for the strategies of higher institutions and new energy industries were shown in Fig. 2. It is shown that $(0,1)$ and $(1,0)$ are unstable points, $(1/2,5/7)$ is a saddle point, $(0,0)$ and $(1,1)$ are ESSs, thus higher institutions and new energy industries finally will simultaneously play "synergistic innovation" strategy or "conventional cooperation" strategy. Fig. 3 (a) depicted the evolutionary paths for the strategy of higher institutions, it can be found that if the probability of new energy industries initially following "synergistic innovation" strategy is 0.7, the result of (synergistic innovation, synergistic innovation) can be acquired only when the probability of higher institutions initially following "synergistic innovation" strategy is equal or more than 0.4; if the probability is 0.3, the result of (synergistic innovation, synergistic innovation) can be acquired only when the probability of higher institutions initially following "synergistic innovation" strategy is equal or more than 0.9. Based on the evolutionary paths for the strategy of new energy industries shown in Fig. 3 (b), for new energy industries, the initial probability of following "synergistic innovation" strategy should be equal or more than 0.5 to achieve the result of (synergistic innovation, synergistic innovation), when the initial probability of higher institutions following "synergistic innovation" strategy is 0.7; the initial probability of following "synergistic innovation" strategy should be equal or more than 0.8 to achieve the result of (synergistic innovation, synergistic innovation), when the initial probability of higher institutions following "synergistic innovation" strategy is 0.3. In summary, the rate of convergence of the strategies for achieving the result of (synergistic innovation, synergistic innovation) will increase when there is a smaller probabilistic distance between the initial strategy and "synergistic innovation" strategy.

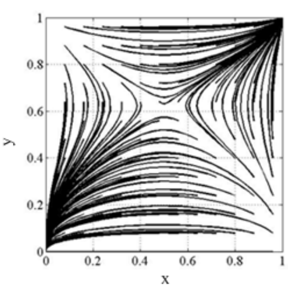
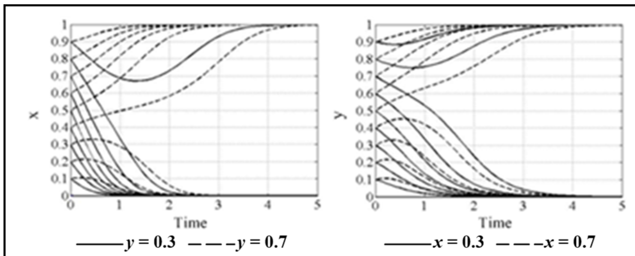


Fig. 2. Dynamic evolutionary paths for the strategies of higher institutions and new energy industries



(a) Strategy of higher institutions (b) Strategy of new energy industries

Fig. 3. Evolutionary paths for each of the strategies of higher institutions and new energy industries

V. Conclusions and Suggestions

The main findings of this study are outlined as follows. (1) There are two ESSs for higher institutions and new energy industries: (synergistic innovation, synergistic innovation), (conventional cooperation, conventional cooperation). (2) The factors influencing the synergistic cultivation of high-level engineering management talents are synergistic innovation benefit, synergistic innovation cost and the benefit from opportunism. Furthermore, the probability of converging on (synergistic innovation, synergistic innovation) is negatively influenced by synergistic innovation cost and the benefit from opportunism, but positively influenced by synergistic innovation benefit. (3) The rate of convergence of the strategies for achieving the result of (synergistic innovation, synergistic innovation) will increase when there is a smaller probabilistic distance between the initial strategy and "synergistic innovation" strategy.

The following suggestions were put forward in order to realize the synergistic innovation between higher institutions and new energy industries on the cultivation of high-level engineering management talents.

(1) Establish a synergistic innovation mechanism of mutual trust. The cooperation will be unstable when one side sincerely cooperate with each other and another side hope to acquire benefit from opportunism, thus they finally will adjust their strategies to converge on (synergistic innovation, synergistic innovation) or (conventional cooperation, conventional cooperation). In fact, an important premise of the result of (synergistic innovation, synergistic innovation) is that there are no opportunistic behaviors on either side. Therefore, higher institutions and new energy industries should establish a synergistic innovation mechanism of mutual trust. They can express trust to each other by sharing information, finishing their tasks efficiently, oral commitment, written commitment, and so on. In summary, the establishment of the synergistic innovation mechanism of mutual trust will contribute to reducing opportunistic behaviors, and increasing the probability of converging on "synergistic innovation" strategy.

(2) Build a distribution system of benefit and risk sharing. The synergistic cultivation of high-level engineering management talents is an activity with high risk and high benefits, thus it is necessary for higher institutions and new energy industries to build a distribution system of benefit and risk sharing, and realize the periodic and targeted distribution of benefit and risk. For instance, new energy industries can prepay higher institutions research and development fees to share research and development risks, new energy industries should reduce the prepayment of technology transfer fees to let higher institutions share the technology transfer risks, higher institutions can become the shareholders by contributing the technology to new energy industries, and written agreements can be signed to determine the distribution method of benefit and risk sharing.

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