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Research on the Promotion Mechanism of Clean Energy Technology in Industrial Parks Based on Evolutionary Game

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Abstract. Clean energy technology is a new energy technology that is developed with good environmental benefits in terms of renewable energy and efficient clean utilization of coal. The industrial park clean energy technology promotion mechanism is an evolutionary game process between an industrial park management committee and a clean energy technology supplier. Based on the basic principles of evolutionary game, this paper constructs a clean energy technology promotion mechanism, analyzes the factors affecting the strategic choice of industrial park management committee and clean energy technology supplier, and constructs industrial park management committee and clean energy technology supplier game matrix under different strategies. Through theoretical analysis and numerical simulation, provides recommendations for the promotion of clean energy technologies.

1. Introduction

With China's economic development entering a new normal, China's energy development faces many bottlenecks such as serious air pollution from coal-fired power generation, outstanding abandonment of wind and solar, natural gas low application rate. Traditional energy technologies are difficult to effectively solve the problems in current energy supply and demand. With the promotion of "Made in China 2025" and the promotion of new technologies such as artificial intelligence, big data, and cloud computing, energy users are increasingly demanding low-carbon energy. In this context, clean energy technologies can be a viable path to solving current energy problems by developing new technologies such as renewable energy and efficient clean utilization of coal. At present, scholars' research on clean energy technologies mainly focuses on experimental analysis, economic benefit analysis, case analysis, etc., and there are few studies on the promotion mechanism of clean energy technologies. Therefore, research on the promotion mechanism of clean energy technologies is the focus of future work.

The industrial park is an internal requirement of the government according to its own economic development. It draws a region through administrative means, gathers various production factors, conducts scientific integration within a certain space, enhances the intensive intensity of industrialization, highlights industrial characteristics, and optimizes the production of functional layout. According to the 2017 statistics of the China Report Hall, there are 478 state-level economic development zones, export processing zones, and bonded zones. There are 1,170 provincial-level development zones and more than 22,000 industrial parks across the country. For an industrial park, by promoting clean energy technologies, renewable energy utilization rates can be increased to achieve energy conservation and emission reduction targets and ecological civilization construction



goals. Due to the differences in the rational level of industrial park management committees and clean energy technology suppliers, the existence of barriers to entry and promotion, and external economics, the promotion of clean energy technologies is difficult to achieve through automatic adjustment of market mechanisms. In the process of promoting clean energy technology, the policy design and selection of the Industrial park management committee will greatly affect the game situation; under different policy systems, the income expectations of the parties will be different, correspondingly the game strategy is also constantly adjusted. On the one hand, clean energy technology suppliers will take corresponding actions according to the characteristics of the policy to decide whether to enter the industrial park; on the other hand, the industrial park management committee evaluates the effectiveness of the policy according to the implementation of the policy, judges the future development trend, and There are policies to make corresponding adjustments. Therefore, this process can be seen as an evolutionary game.

The evolutionary game theory was first proposed by British scholar Magnard [1]. In recent years, evolutionary games have had new applications and innovations in theoretical and applied research. For example, Kleshnina, Fila and Ejov [2] studied the problem of evolutionary stability strategy (ESS) under imperfect conditions, and found that imperfect situations can change the outcome of the game and its dynamics. Sujatha and Usha [3] based on evolutionary game theory to explain and predict the social and economic sustainability of the public health insurance supply chain with evolutionary game problems with random disturbances. Luo and Jiang [4] studied the co-evolution of resources and cooperation in the space evolution game. Kolokoltsov [5] studied the effects of interference, resistance, and cooperation on participants in evolutionary games. Hadzibeganovic, Stauffe, and Han [6] studied the effects of enhanced cooperation mechanisms and signal guidance on the evolutionary game outcomes and their dynamics. Liu, Pan, and He [7] proposed a policy update rule driven by local information. Through research, it is found that local information is conducive to promoting cooperation to a certain extent. Wang [8] analyzed the evolution process and trend of the behaviour of the participants in the sharing economy from the perspective of evolutionary game. Cao [9] based on the evolutionary game method to analyze the interaction behaviour of construction land use in urbanized areas and agricultural areas and simulate the simulation with empirical data. Ge, Zhang and Zhao [10] based on the evolutionary game theory, constructed a benefit model between the government, the enterprise and the public. Wang, Chen and Li [11] extended the incentive mechanism to the constraints and established an evolutionary game model between the central and local governments, local governments and enterprises. Huang and Liu [12] constructed an evolutionary game model between community and local governments for environmental compensation in the construction of adjacent facilities.

In summary, scholars have done a lot of research on clean energy technology and evolutionary games, but they are less used in project promotion mechanisms involving government-enterprise relations. Based on the existing research, this paper uses the basic principles of evolutionary game to construct a clean energy technology promotion mechanism innovatively, and demonstrates the influence of different initial conditions on the evolution results through numerical simulation.

2. Clean energy technology promotion mechanism model

2.1 Influencing factors analysis

2.1.1. *Clean energy technology suppliers influencing factors* Expected profit π : the main driving force for clean energy technology suppliers to enter the industrial park, $\pi = \alpha I$, where, α is profit margin, I is the total income.

Entry fee F : mainly includes project construction costs, illegal technology transfer, and daily operating expenses.

Industrial park management committee Reward R_M : Clean energy technology suppliers receive financial subsidies from the industrial park management committee for promoting clean energy technologies.

2.1.2. *Industrial park management committee influencing factors* Tax T : the promotion of clean energy technology will bring tax revenue to the industrial park management committee, $T = \beta I$, where, includes a comprehensive tax rate for all taxes such as corporate income tax, business tax and value-added tax.

Industrial park management committee reward R_M : Includes the Industrial park management committee accepting transfer payments from higher levels of government and the Industrial park management committee's expenditure on financial subsidies for the promotion of clean energy technologies. This paper assumes that the incentive fee for clean energy technology is proportional to the industrial park management committee accepting transfer payments from higher levels of government, $R_M = \kappa R_U$, $1 \geq \kappa > 0$, (M is defined as industrial park management committee, U is defined as superior government).

Environmental benefits E : through clean energy technologies, industrial park users use renewable energy in the process of energy use and obtain good environmental benefits. $E = \lambda I$, where, λ is defined as the environmental benefits of the output value of clean energy technology units.

Promotion cost C : the cost incurred by the Industrial park management committee in the process of promoting clean energy technology, inspection, negotiation, coordination, etc.

Time value H : time value loss before and after the promotion of clean energy technology. Assumption: The promotion policy of the industrial park management committee enables clean energy technology to be put into production quickly.

2.2. *Game matrix*

M is defined as the Industrial park management committee, and S is defined as Multi-energy Complementary Project Supplier, where P_1 indicates the probability of the clean energy technology supplier entering the industrial park, and P_2 indicates the strength of the industrial park management committee to promote clean energy technology. The game matrix is shown in Table 1.

Table 1. Game matrix

		Clean energy technology supplier	
		Enter P_1	Not enter $1-P_1$
Industrial park management committee	Promotion	$Q_M = \beta I + R_U - \kappa R_U + \lambda I + H - C$	$Q_M = -C$
	P_2	$Q_E = (\alpha - \beta) I + \kappa R_U - F$	$Q_S = 0$
	Not promotion	$Q_M = \beta I + \lambda I + R_U$	$Q_M = 0$
	$1-P_2$	$Q_E = (\alpha - \beta) I - F$	$Q_S = 0$

3. Model solution

3.1. *Income function construction*

3.1.1 *Clean energy technology suppliers income function*

$$E_{Enter} = P_2 [(\alpha - \beta) I + \kappa R_U - F] + (1 - P_2) [(\alpha - \beta) I - F] = P_2 \kappa R_U + (\alpha - \beta) I - F \tag{1}$$

$$E_{Not\ enter} = 0 \tag{2}$$

$$E_{Suppliers} = P_1 E_{Enter} + (1 - P_1) E_{Not\ enter} \tag{3}$$

3.1.2 Industrial park management committee income function

$$\begin{aligned} E_{Promotion} &= P_1(\beta I + R_U - \kappa R_U + \lambda I + H - C) + (1 - P_1)(-C) \\ &= P_1(\beta I + R_U - \kappa R_U + \lambda I + H) - C \end{aligned} \tag{4}$$

$$E_{Not\ promotion} = P_1(\beta I + \lambda I + R_U) + 0 = P_1(\beta I + \lambda I + R_U) \tag{5}$$

$$E_{Committee} = P_2 E_{Promotion} + (1 - P_2) E_{Not\ promotion} \tag{6}$$

3.2 Model solution

3.2.1 Clean energy technology suppliers model solution. Clean energy technology replication technology dynamic equation is

$$F(P_1) = \frac{dP_1}{dt} = P_1(E_{Enter} - E_{Suppliers}) = P_1(1 - P_1)(P_2 \kappa R_U + (\alpha - \beta)I - F) \tag{7}$$

$$F'(P_1) = \frac{dP_1}{dt} = (1 - 2P_1)(P_2 \kappa R_U + (\alpha - \beta)I - F) \tag{8}$$

Order $F(P_1) = \frac{dP_1}{dt} = 0$, solution $P_1^* = 0$, $P_1^* = 1$, $P_2^* = \frac{(\alpha - \beta)I - F}{-\kappa R_U}$.

When $P_2 = \frac{(\alpha - \beta)I - F}{-\kappa R_U}$, then $F(P_1) = 0$, $F'(P_1) = 0$, all y-axis levels are stable, the promotion

of industrial park management committees is reached $P_2^* = \frac{(\alpha - \beta)I - F}{-\kappa R_U}$, and the possibility of clean

energy technology suppliers entering industrial parks is stable. When $P_2 > \frac{(\alpha - \beta)I - F}{-\kappa R_U}$, for $P_1^* = 0$,

$P_1^* = 1$, then $F'(0) > 0$, $F'(1) < 0$, $P_1^* = 1$ is the only evolutionary stability strategy at the moment; when the promotion policy of the Industrial park management committee reaches a certain level and shows an increasing trend, the possibility of clean energy technology entering the industrial park is gradually increasing, and finally Entering the industrial park is the best choice for clean energy

technology suppliers. When $P_2 < \frac{(\alpha - \beta)I - F}{-\kappa R_U}$, For $P_1^* = 0$, $P_1^* = 1$, then $F'(0) < 0$, $F'(1) > 0$, is the

only evolutionary stability strategy at the moment $P_1^* = 0$; when the promotion policy of the Industrial park management committee does not reach a certain level and shows a downward trend, the possibility of clean energy technology entering the industrial park is gradually reduced. Not entering is the best choice for suppliers of clean energy technologies. The dynamic trends and stability of clean energy technology suppliers entering industrial parks are shown in Figure 1.

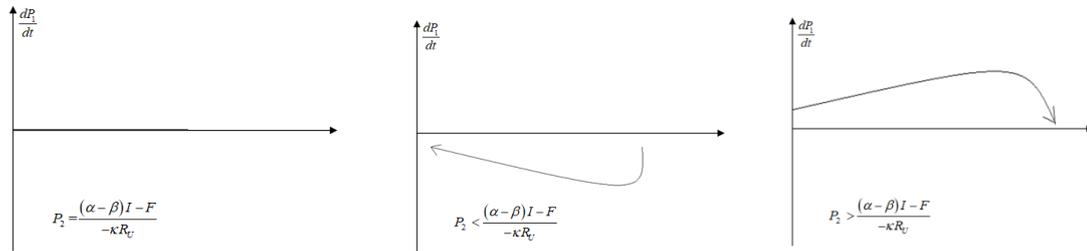


Figure 1. Clean energy technology suppliers decision-making evolution process

3.2.2 *Industrial park management committee model solution.* Industrial park management committee replication dynamic equation is

$$F(P_2) = \frac{dP_2}{dt} = P_2 (E_{Promotion} - E_{Committee}) = P_2 (1 - P_2) [P_1 (H - \kappa R_U) - C] \tag{9}$$

$$F'(P_2) = \frac{dP_2}{dt} = (1 - 2P_2) [P_1 (H - \kappa R_U) - C] \tag{10}$$

Order $F(P_2) = \frac{dP_2}{dt} = 0$, solution $P_2^* = 0$, $P_2^* = 1$, $P_1^* = \frac{C}{H - \kappa R_U}$.

When $P_1 = \frac{C}{H - \kappa R_U}$, then $F(P_2) = 0$, $F'(P_2) = 0$, all y-axis levels are stable; when the

possibility of clean energy technology entering the industrial park is reached $P_1^* = \frac{C}{H - \kappa R_U}$, the

industrial park management committee's efforts to promote the policy are stable. When $P_1 > \frac{C}{H - \kappa R_U}$

, for $P_2^* = 0$, $P_2^* = 1$, then $F'(0) > 0$, $F'(1) < 0$, $P_2^* = 1$ is the only evolutionary stability strategy at the moment; when the possibility of clean energy technology entering the industrial park is large enough and increasing, the Industrial park management committee will enter the industrial park for clean

energy technology. When $P_1 < \frac{C}{H - \kappa R_U}$, for $P_2^* = 0$, $P_2^* = 1$, then $F'(0) < 0$, $F'(1) > 0$, $P_2^* = 0$ is the

only evolutionary stability strategy at the moment. When the possibility of clean energy technology entering the market is small enough and showing a decreasing trend, the Industrial park management committee gives the clean energy technology access to the industrial park. The promotion is getting smaller and smaller. At this time, reducing the promotion is the best choice for the industrial park management committee.

The dynamic trend and stability of the promotion of the industrial park management committee is shown in Figure 2.

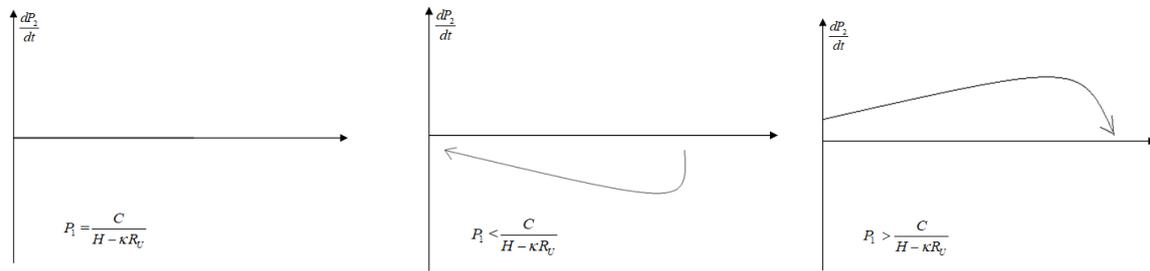


Figure 2. Industrial park management committee decision-making evolution process

3.2.3 *Mixed model solution.* In summary, the dynamic relationship of the two sides of the game is represented by a two-dimensional plane coordinate, as shown in Figure 3.

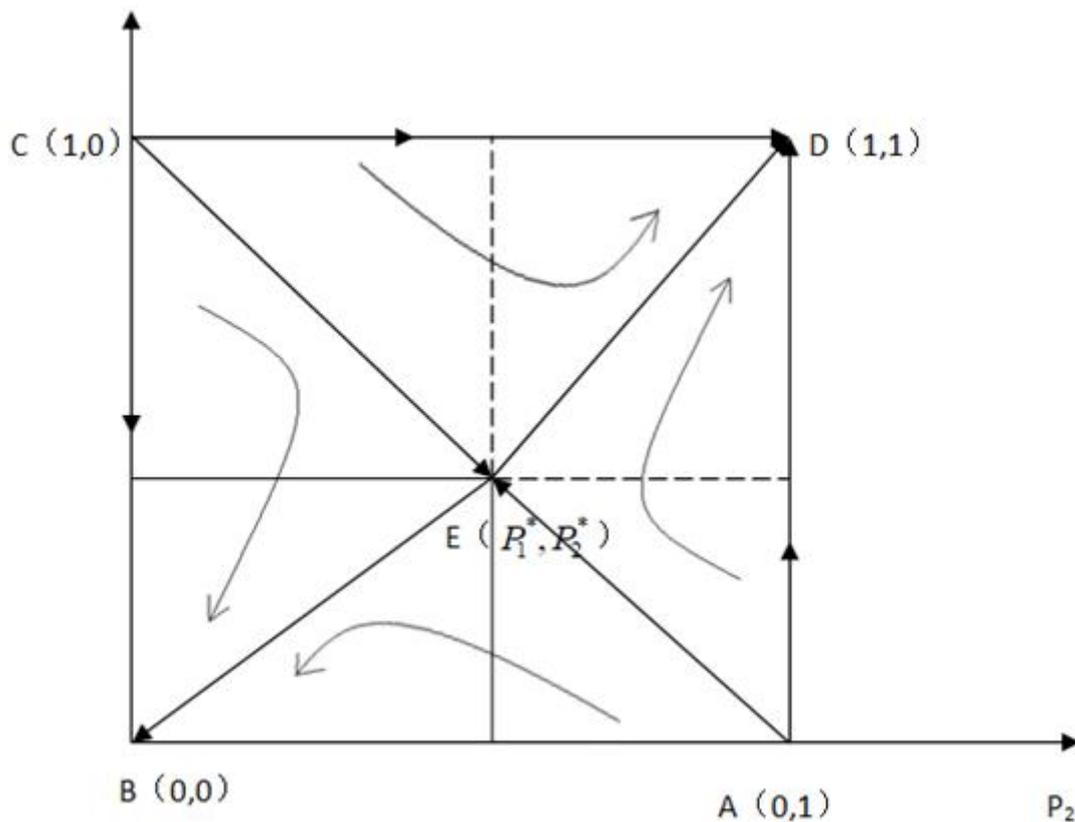


Figure 3. Decision-making evolution process of both sides in the game

In Figure 3, points B and D are evolutionary stabilization strategies. Point B indicates that the Industrial park management committee does not adopt a promotion policy, and clean energy technology suppliers do not enter the industrial park. Point D indicates that the Industrial park management committee has adopted a vigorous promotion policy, and clean energy technology suppliers have actively entered the industrial park. In the upper right area of Figure 3, the behaviour of both parties converges to point D, ie the system converges to the Pareto optimal equilibrium D (1, 1). In the lower left area of Figure 3, the behaviour of both parties converges to point B, that is, the system converges to Pareto poor balance B (0, 0).

When the system is converge to the Pareto optimal equilibrium D (1,1)with the greatest probability, at this time $P_1 > \frac{C}{H - \kappa R_U}$, $P_2 > \frac{(\alpha - \beta)I - F}{-\kappa R_U}$. In $P_2^* = \frac{(\alpha - \beta)I - F}{-\kappa R_U}$, expected profit $\pi = \alpha I$, industrial park management committee incentive fee $R_M = \kappa R_U$, has a positive relationship with P_2^* . The tax revenue of the industrial park $T = \beta I$, entry fee F , has a negative relationship with P_2^* . The Industrial park management committee can appropriately increase the incentive fees and lower the tax rate and other methods, make $P_2 > P_2^*$. When $P_2 > P_2^*$, the best choice for clean energy technology suppliers is to enter the industrial park. In $P_1^* = \frac{C}{H - \kappa R_U}$, the promotion cost C , the direct reward from the industrial park management committee $R_M = \kappa R_U$, has a positive relationship with P_1^* ; the time value H with P_1^* has a negative relationship. It is possible to increase the direct incentives from the Industrial park management committee and increase the coordinated support of the industrial park management committee for clean energy technologies, make $P_1 > P_1^*$. When $P_1 > P_1^*$, the most choice of the Industrial park management committee was to increase the promotion.

The strategic choice of the comprehensive industrial park management committee and clean energy technology, when the behavioural probability of both sides exists in the upper right area of Figure 3, it automatically converges to the Pareto optimal equilibrium D (1, 1).

4. Numerical simulation

This paper uses Matlab software to simulate the dynamic evolution process of its strategy selection under different initial conditions. Assume that the values of the parameters in the game payment matrix are as follows: total income of clean energy technology $I = 3$ million Yuan, profit rate $\alpha = 0.5$, entry cost $F = 3$ million Yuan, incentive fee from higher level government $R_U = 5$ million Yuan, distribution coefficient $\kappa = 0.8$, including the corporate income tax, business tax, value-added tax and other taxes, the comprehensive tax rate $\beta = 0.3$.

According to the formula $P_2^* = \frac{(\alpha - \beta)I - F}{-\kappa R_U}$, $P_2^* = \frac{(0.5 - 0.3) \times 300 - 300}{-0.8 \times 500} = 0.6$, the

dynamic evolution of the strategy of clean energy technology strategy is as follows:

(1) If $P_2 < 0.6$, in this case $P_2 = 0.4$, the dynamic evolution of the clean energy technology supplier's entry strategy over time is shown in Figure 4. It can be seen from the figure that the clean energy technology supplier's entry strategy finally converges to zero under the initial probability of each promotion strategy. That is, when the industrial park management committee chooses to promote less, the clean energy technology will eventually adopt a non-entry strategy.

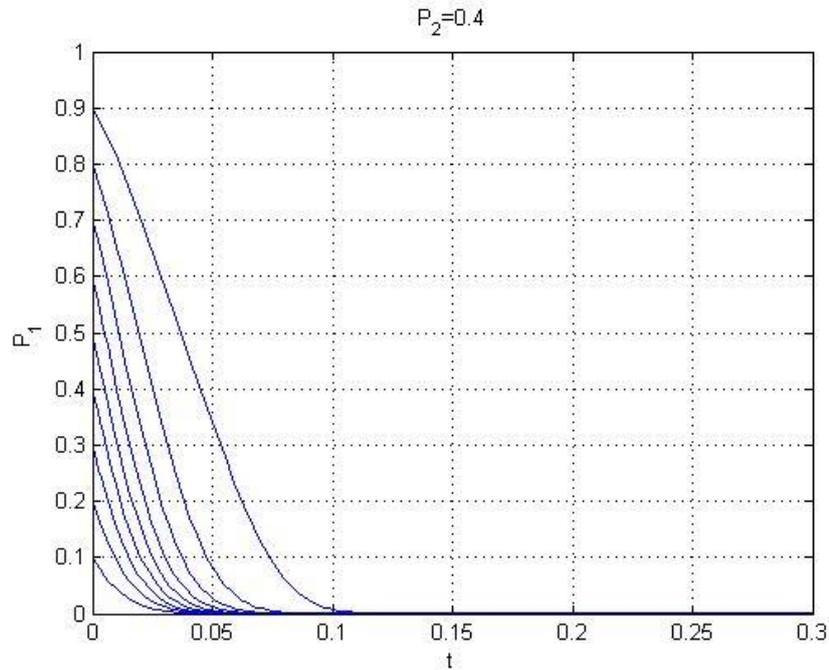


Figure 4. Dynamic evolution process ($P_2=0.4$)

(2) If $P_2 > 0.6$, in this case $P_2=0.8$, the dynamic evolution of the clean energy technology supplier's entry strategy over time is shown in Figure 5. It can be seen from the figure that under the initial probability of each promotion strategy, the entry strategy of the clean energy technology will eventually converge to 1, that is, when the promotion of the industrial park management committee is greater, the clean energy technology will eventually adopt the entry strategy.

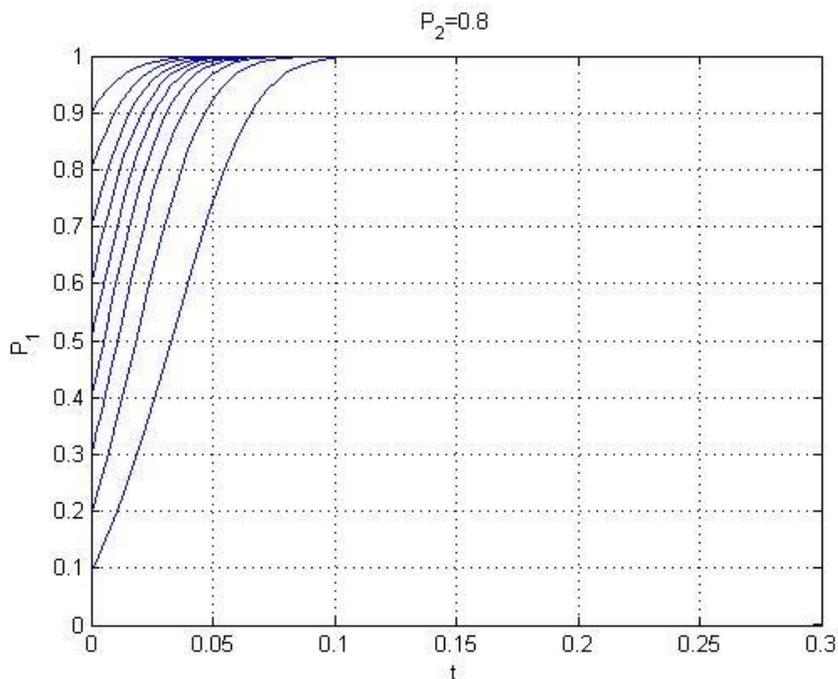


Figure 5. Dynamic evolution process($P_2=0.8$)

5. Conclusion

The long-term and arduous nature of China's energy supply and demand contradiction determines the importance of building a clean energy technology promotion mechanism. Using the basic idea of evolutionary game to analyze the decision-making behaviour of industrial park management committee and clean energy technology supplier, the research results show that:

(1) The incentive measures adopted by the Industrial park management committee for clean energy technologies are the key to whether clean energy technology suppliers enter industrial parks; the decision-making behaviour of clean energy technology suppliers is subject to the promotion of industrial park management committees in fluencies;

(2) The Industrial park management committee can encourage suppliers to promote clean energy technologies. The policy selection of the Industrial park management committee can make the clean energy technology promotion mechanism fully play its role, such as appropriately increasing incentive fees, reducing tax interest rates, and increasing coordination and support. Thus, both industrial park management committee and clean energy technology supplier achieving the optimal balance of the economic and social development.

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