Heliyon 10 (2024) e36618

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

An evolutionary game analysis of incentive of industrial parks, government support and enterprise innovation willingness in China

Jie Zhen [a,1], Juan Ouyang [b,*,2], Lan Wang [a,1]

[a] Business School, East China University of Political Science and Law, Shanghai, 201620, China
[b] Business School, Yunnan University of Finance and Economics, Kunming, 650221, China

A R T I C L E I N F O

Keywords:
Innovation
Industrial parks
Evolutionary game
High-quality development

A B S T R A C T

Industrial parks are the important carriers to promote regional innovation and economic development. The policy preferences of the government, the support orientation of the industrial park and the innovation willingness of the enterprises in the park play a significant role in promoting the high-quality development of the industrial parks. In order to clarify the decision-making process of each subject, this paper constructs a triple evolutionary game model between the government, industrial park and enterprises in the park, Matlab software is used to conduct simulation research, and the strategy selection of each subject in the process of promoting high-quality development of the park is analyzed, as well as the influence of variables on the evolutionary game. Through numerical simulation, this study finds that the strategy choice of the government and the industrial park is influenced by the cost of innovation management for enterprises. In addition, the innovation willingness of enterprises is affected by the policy preference of the government and the support orientation of the industrial park, the excessive tax preference of the government will lead to negative innovation behaviors of the enterprises, the "inward incentives" support orientation of the industrial park can stimulate the enterprises' innovation willingness on "active innovation", the enterprises behavior of "active innovation" will strengthen the "inward incentives" support orientation of the industrial park in turn. The difference of the benefits and the costs between the two support orientations by the industrial park will lead to the equilibrium points stabilized at different strategy combinations. Based on these findings, countermeasures and suggestions are proposed in this study.

1. Introduction

In 2022, the 20th National Congress of the Communist Party of China made high-quality development as the primary task of overall building a modern socialist country. High-quality development is an important category of XI Jinping economic thought, and in terms of connotation, it mainly refers to the development in which innovation becomes the primary driving force and coordination becomes an endogenous feature. As the important carrier and agglomeration of innovation development and industrial transformation,

* Corresponding author. Business School, Yunnan University of Finance and Economics, 237 Longquan Road, Wuhua District, Kunming, China.
E-mail address: grace_ouyang@yeah.net (J. Ouyang).
[1] Business School, East China University of Political Science and Law, 555 Longyuan Road, Songjiang District, Shanghai, China.
[2] Business School, Yunnan University of Finance and Economics, 237 Longquan Road, Wuhua District, Kunming, China.

https://doi.org/10.1016/j.heliyon.2024.e36618
Received 30 June 2023; Received in revised form 7 August 2024; Accepted 20 August 2024
Available online 23 August 2024

industrial parks have made a significant contribution in the process of innovation development [1,2]. Furthermore, the high-quality development of industrial parks refers to the development process of adhering to the direction of "developing high-tech and realizing industrialization," deepening institutional reform and creating a good innovation and entrepreneurship ecology as the starting point, cultivating and developing enterprises and industries with international competitiveness as the focus, and focusing on scientific and technological innovation as the core. Since 2013, the innovation development of industrial parks in China has broadly maintained a steady growth of over 6 %, and in some years the growth rate exceeded 14 % [3]. In particular, as the main body of innovation in industrial parks, the enterprises have always been the most innovative groups. In 2021, the R&D expenditure of enterprises in 169 national high-tech zones accounts for 49.2 % of that of the whole country, in addition, 36.8 % of high-tech enterprises in China are clustered in the national high-tech zones [4].

In the process of innovation development, both the industrial parks and local government have adopted incentive policies to promote enterprise innovation [5]. These policies cover almost all links in the process of enterprise innovation, including business incubation services and tax incentives for new ventures at the initial stage, and R&D alliance promotion, innovation platform building and financing channels unimpeded at the development stage. However, in the practice of innovation in the park, these efforts to promote innovation are still faced with urgent problems. First, the promotion effect of innovation incentive policy mostly comes from qualitative experience, and there is no clear support mode or scope of support strength, and even the negative effect may occur in the application process. Second, innovation incentive policies tend to be similar among the parks and the local governments, resulting in low-level competition among the parks and resource waste at the overall level. Third, compared with the requirements of "innovation-driven development", there are still large gaps in the innovation of the enterprises in industrial parks. Especially, industrial parks are facing serious challenges in promoting independent innovation and breaking through stranglehold technical problems.

From the perspective of system dynamics, the high-quality development of industrial parks in China has entered the early stage of the formation of an innovation ecosystem [3]. The parks begin to pay attention to the multi-agent interaction among the enterprises, universities, scientific and technological financial service institutions, and emphasize the interactive and networked characteristics of innovation activities, which eventually forms a collaborative innovation network [6–8]. However, in this system, innovative subjects and their behaviors are becoming more diversified and innovation activities are becoming more complex [9]. Therefore, the research on the innovation in the parks should have a strategic top-level design perspective, and concern the multiple interest demands of key innovative subjects and their coordination and cooperation, so as to avoid the adverse situation of "fragmentation", "decentralization" and "mutual cancellation of innovation achievements" [4].

Accordingly, the purpose of this study is to form a multi-agent interactive theoretical framework for the high-quality development of the industrial parks. For this purpose, the paper constructs an evolutionary game model formed by the government, the industrial park and the enterprises in the park, to discuss the policy preference of the government, the support orientation of the industrial park and the innovation willingness of the enterprises in the park in the process of high-quality development. By analyzing the benefits and costs of the government, industrial park and enterprises under different strategies, and solve the corresponding evolutionary stability points of each subject, so as to reveal the decision-making process of the core subjects in the high-quality development of industrial parks. The results of this study are of great significance for the government and the industrial park to formulate and select innovation incentive policies and maximize the effectiveness of innovation. Therefore, the research contribution of this paper mainly focuses on the following two aspects: Firstly, the industrial park is taken as a specific important background to analyze the enterprise innovation, and the industrial park, the government and the enterprise are taken as the three main bodies affecting the innovation, so as to systematically analyze the innovation process; Secondly, the paper pays attention to the important behavioral performance of the innovation subjects in the innovation process, and clarifies the main behavioral strategies of each innovation subject with the method of evolutionary game, so as to find the stable strategy combination of the tripartite game under the goal of high-quality development.

From the perspective of innovation ecology and system management, this paper differs from the previous studies from three points: firstly, it focuses on three important innovation subjects which are the enterprise, the industrial park and the government, avoiding the one-sidedness caused by the analysis of innovation process by a single entity of the enterprise; Secondly, this paper analyzes the specific performance of the three subjects in the process of innovation, and condenses the content of their choices with the strategic space in the evolutionary game; Thirdly, based on the relevant contents of the system dynamics method, the paper deeply analyzes the specific impact of the subjects on innovation, which is conducive to the selection of efficient innovation strategies in the innovation development of the industrial park.

2. Literature review

Industrial parks have played the role of economic growth poles and innovation centers in China's reform and opening up [3], and continue to play an important role in innovation and development, which is mainly reflected in the four stages of the park development. Firstly, in the initial cultivation period from 1984 to 1991, relevant researches focused on the uniqueness of the park's encouragement of enterprise innovation with preferential policies [10]. Secondly, in the period of rapid development from 1992 to 2002, more studies found that the parks and governments promoted enterprise innovation by means of institutional construction [11] and assessment [12]. Thirdly, during the period of stabilization and consolidation from 2003 to 2008, the research results show that the parks and governments paid attention to science and technology policy [13], governance mode [14], ecological development [15] and so on, trying to improve the innovation ability of the enterprises. Fourthly, in the period of innovation development since 2009, scholars focused on the research of innovation mechanism [16], innovation efficiency [17]and innovation network [18,19], and pay more attention to the perspective of cooperation or synergy [20,21]. In general, scholars have made some achievements in the research on enterprise innovation in the context of industrial parks, but have not yet formed a systematic analysis framework. On this basis, this part will sort out the incentive role of the government and industrial parks in enterprise innovation, and make clear the necessity of in-depth analysis of the relationship between innovation subjects by evolutionary game method.

2.1. Government policy preference to promote enterprise innovation

The enterprises' innovation can achieve extensive knowledge sharing and form technology spillover effects [22,23]. However, the technology spillovers may also generate "imitation effects", which may even lead to a decrease in enterprises' motivation to innovate. Therefore, on the one hand, the enterprises can adjust their innovation strategies, on the other hand, the enterprises are increasingly influenced by the external environment, especially by the local government [24] and the industrial parks.

Government incentives have an important role in enterprises' innovation [25], playing the functions of overall coordination and supervision, and providing infrastructure, financial support, and policy guarantees for enterprises' innovation [24]. There are two main kinds of incentives for the government to promote enterprises' innovation, government subsidies or tax incentives, yet the existing relative studies have not been able to answer the question of "which is more beneficial". On the one hand, government subsidies belong to supply-oriented innovation policies [26], and ex-ante support to enterprises may produce "cost-reduction effect" or "financing effect" [27], alleviates the opportunity cost pressure of enterprises engaging in R&D activities, and diffuses the business risks brought by financing [28], that is, direct funding has a stronger role in promoting innovation [29]. On the other hand, government subsidies may distort the prices of innovative input elements, and some enterprises may even engage in rent-seeking [30] or "speculative subsidy fraud" in order to obtain subsidized projects. At the same time, government subsidies may also have a crowding-out effect on firms' normal R&D expenditures [28]. Similarly, tax incentives belong to indirect subsidies and environment-oriented innovation policies [26], which provide ex-post support to the enterprises. Although such policies meet the demand of high-quality innovation capacity development for the enterprises, the stronger the innovation capacity of the enterprises, the less they depend on innovation policies [28]. Moreover, tax reduction and exemption play an insignificant role in promoting enterprises' innovation in some cases, and even sometimes has a curbing effect [29].

2.2. Industrial parks measurements to encourage enterprise innovation

From the perspective of industrial parks, introducing incentive measures and building innovation platforms to attract talents and other innovation resources are important ways for the parks to promote innovation development. It has been suggested that the knowledge flow [31], information exchange [32] and thereout knowledge governance [33–35] and innovation ecosystem [22,36] constantly promote the development of innovation activities. Further, some scholars have studied the innovation capacity [37], innovation efficiency [38,39], and innovation network [40–42] of industrial parks. However, these studies have focused more on the form or outcome of innovation, and moreover, both scholars and practitioners have emphasized more on the attraction of innovation resources outside the park or the division of labor and collaboration between the park and external regions [43,44], while relatively neglected the cultivation of innovation power inside the park.

Of course, the existing literature has concerned about the activities of certain types of subjects in industrial park innovation, such as the targeted intervention of the government [24], the phased evolution of the park [25] and the development of innovation networks of enterprises. The scholars have researched the innovation in terms of actor roles [45] and cross-border resource integration [46]. Further, there are also some studies that have analyzed the competing and cooperation relationships among innovative subjects [47], the coordination interaction [48], and the formation of value creation and co-evolutionary networks by multiple agents [24,25]. However, in general, these researches have not really studied industrial park innovation in depth at a system perspective including the regional level, the park level, and the enterprise level [22,36], and there is also a relative lack of system-level analysis on innovation mechanism [49,50].

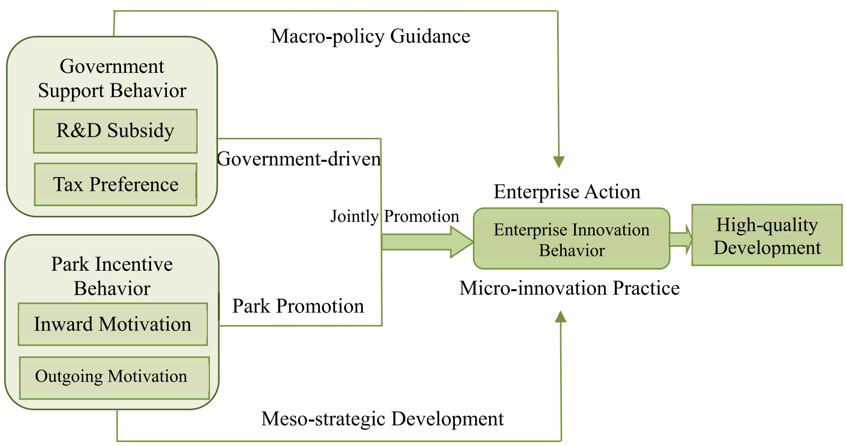

Fig. 1. Game logic relationship of the three parties for industrial parks' high-quality development.

2.3. Evolutionary game analysis in the high-quality development of industrial parks

The existing studies mainly use empirical analysis methods and try to use fuzzy neural network, social network [51], entropy theory [43] and other analytical methods to conduct research on industrial parks' development. Also, some researches have applied evolutionary game models to analyze the factors influencing government behavior and enterprises' innovation [24]. However, these studies simply define the government's strategy set as supportive or non-supportive, and the enterprises' strategy set as innovative or non-innovative, which does not consistent with the current reality of innovation. Besides, the existing studies ignore the industrial park as an important subject of innovation.

The high-quality development of industrial parks is a process of muti-participation and dynamic evolution [52], to analyze the mutual feedback and evolutionary stabilization strategies of each party in the process of high-quality development, this paper adopts the evolutionary game approach, taking into account the limited rationality and strategic choices of each subject [53], and systematically constructs a three-party evolutionary game model of the government, the industrial park and the enterprises in the park. we aims to analyze the role of each subject in achieving innovation-driven development from a meso-perspective, focuses on the policy preference of the government, the support orientation of the industrial park and the innovation willingness of the enterprises in the park, and consequently solve the corresponding evolutionary stability points of the three parties (as shown in Fig. 1), so as to provide useful countermeasures and suggestions for the policy orientation of the government and industrial parks.

3. Construction of the evolutionary game model

3.1. Problem description

Evolutionary game theory is based on bounded rationality of the decision makers who can only adjust their strategies according to existing payoff information [53]. For this reason, the theory focuses on the mutual feedback effects of driving forces among different decision makers and specifies evolutionary stabilization strategies [54]. To further promote innovation development, industrial parks have increased their efforts to attract high-technology talents, flexibly introduced academicians and other experts in the leading industrial fields to work in the parks. However, some industrial parks have found that such outward incentive strategies are not only costly, but also do not bring about the effectiveness of using talents for the park. Instead, better results are obtained when incentives are given to talents within the park. Therefore, by constructing an evolutionary game model, this paper explores the interaction among the policy preference of the government, the support orientation of the industrial park and the innovation willingness of the enterprises in the park, and finally disclose the decision process of each subject in the high-quality development of industrial parks, the logical relationship of the three parties in the evolutionary game is shown in Fig. 1.

3.2. Model assumptions

Based on evolutionary game theory, the decision-making strategies of each subject within the industrial park innovation system for high-quality development are analyzed, and the following hypotheses are proposed.

Hypothesis 1. The three parties involving government, industrial parks and enterprises are bounded rational. The strategy choices of the subjects evolve gradually over time and stabilize to the optimal strategy. The government mainly provides help to enterprises through different policy measures, and its strategy space is $S_g =$ (R&D subsidies, tax incentives); The industrial park promotes the innovation development of enterprises through different support orientation, and its strategy space is $S_p =$ (outward incentives, inward incentives); The enterprises decide their innovation willingness based on their own development and the incentive measures of the government and industrial parks, and their strategy space is $S_f =$ (active innovation, negative innovation).

Hypothesis 2. The government uphold a supportive attitude toward innovation, where the probability of providing R&D subsidies is $x \in [0, 1]$ and the probability of choosing tax incentives is 1-x; the probability that industrial parks choose outward incentives is $f \in [0, 1]$ and the probability of choosing inward incentives is 1-f; the probability that enterprises actively participate in innovation is $z \in [0, 1]$ and the probability of choosing negative participation in innovation is 1 -z.

Hypothesis 3. When the government provide R&D subsidy Bgr for enterprises, it tends to direct and ex-ante financial support, and the government's cost of innovation management Cgl is lower. When the government provides tax incentives Bgt for enterprises, it tends to indirect and ex-post innovation support, and the government needs to continuously pay attention to and evaluate enterprises' innovation activities, and the cost Cgh is higher.

Hypothesis 4. When the industrial park mainly adopts outward incentives, the subsidy provided by the park is Bph; When the park mainly uses inward incentives, the subsidy is Bpl. In general, Bph is higher than Bpl in order to attract high-quality innovation resources from outside the park. When the park chooses the "outward incentives" strategy, the park has lower management cost Cpl. When the park chooses the "inward incentives" strategy, the park pays more attention to the process of enterprise innovation as well as evaluates and rewards the innovation performance, thus the cost Cph is higher.

Hypothesis 5. When enterprises actively innovate, they pay the corresponding cost Cf. When the industrial park chooses the "inward incentives" strategy, the additional benefits Re such as business environment optimization and cooperation stickiness enhancement can be generated, and the industrial park will gain the benefit at the same time. In this case, the government will also gain Re no matter which strategy it chooses to support enterprise innovation.

Hypothesis 6. When enterprises actively innovate and the park chooses the "outward incentives" strategy, the enterprises generate a supportive benefit Rs in integrating resources to innovate, the industrial park will obtain the benefit, and the government will also gain the benefit Rs regardless of the strategy it chooses. In general, Re, which stems from close cooperative interactions within the park is higher than Rs.

Hypothesis 7. When enterprises innovate negatively, they do not generate the related costs and benefits.

The above parameters and their descriptions are shown in Table 1.

3.3. Payoff matrix

Based on the above assumptions, this paper constructs a mixed strategy game matrix among government, industrial parks and enterprises, as shown in Table 2.

According to Table 2, the expected gain for the government choosing the "R&D subsidies" strategy is U_{gr}, the expected gain of choosing the "tax incentives" strategy is U_{gt}, and the average gain is $\overline{U_g}$:

$$\begin{cases} U_{gr} = zR_e + fzR_s - C_{gl} - B_{gr} - fzR_e \\ U_{gt} = zR_e + fzR_s - zB_{gt} - C_{gh} - fzR_e \\ \overline{U_g} = xC_{gh} - xB_{gr} - C_{gh} - xC_{gl} - zB_{gt} + zR_e - fzR_e + fzR_s + xzB_{gt} \end{cases} \tag{1}$$

Thus, the replication dynamic equation for the government strategy choice can be obtained as F(x):

$$F(x) = \frac{dx}{dt} = x\left(U_{gr} - \overline{U_g}\right) = x(x-1)\left(B_{gr} - C_{gh} + C_{gl} - zB_{gt}\right) \tag{2}$$

Similarly, the expected gain U_{ph} when the industrial park chooses the "outward incentives" strategy, the expected gain U_{pl} when it chooses the "inward incentives" strategy, the average gain $\overline{U_p}$ and the replication dynamic equation F(f) are respectively:

$$\begin{cases} U_{ph} = zR_s - C_{pl} - B_{ph} \\ U_{pl} = zR_e - C_{ph} - B_{pl} \\ \overline{U_p} = -(1-f)\left(B_{pl} + C_{ph} - zR_e\right) - f\left(B_{ph} + C_{pl} - zR_s\right) \end{cases} \tag{3}$$

$$F(f) = \frac{df}{dt} = f\left(U_{ph} - \overline{U_p}\right) = f(f-1)\left(B_{ph} - B_{pl} - C_{ph} + C_{pl} + zR_e - zR_s\right) \tag{4}$$

The expected gain U_{ey} when the enterprises actively innovate, the expected gain U_{en} when the enterprises negatively innovate, average gain $\overline{U_e}$ and the replication dynamics equation F(z) are respectively:

$$\begin{cases} U_{ey} = B_{gt} + B_{pl} - C_f + R_e - fB_{pl} - fR_e + fR_s + xB_{gr} - xB_{gt} \\ U_{en} = B_{pl} - fB_{pl} + xB_{gr} \\ \overline{U_e} = B_{pl} - fB_{pl} + xB_{gr} + zB_{gt} - zC_f + zR_e - fzR_e + fzR_s - xzB_{gt} \end{cases} \tag{5}$$

$$F(z) = \frac{dz}{dt} = z\left(U_{ey} - \overline{U_e}\right) = -z(z-1)\left(B_{gt} - C_f + R_e - fR_e + fR_s - xB_{gt}\right) \tag{6}$$

Table 1
Parameters and their meaning.

Parameters	Meaning
R_e	Additional benefits such as business environment optimization and cooperation stickiness enhancement when enterprises actively innovate and industrial parks choose the "inward incentives" strategy
R_s	The supportive benefits generated by enterprises in the process of integrating resources to innovate when enterprises actively innovate and the park chooses the "outward incentives" strategy
C_f	Related costs paid by enterprises for active innovation
B_{ph}	The subsidies provided by the park when it mainly adopts "outward incentives" strategy
B_{pl}	The subsidies provided by the park when it mainly adopts "inward incentives" strategy
C_{pl}	The cost of managing enterprises innovation in the park when the park chooses the "outward incentives" strategy
C_{ph}	The cost of managing enterprises innovation in the park when the park chooses the "inward incentives" strategy
B_{gr}	R&D subsidies provided by government departments for enterprises
B_{gt}	Tax incentives provided by government departments for enterprises
C_{gl}	The cost of government managing enterprises innovation when the government chooses the "R&D subsidies" strategy
C_{gh}	The cost of government managing enterprises innovation when the government chooses the "tax incentives" strategy

Table 2
Payoff matrix of the government, industrial park and enterprises.

Strategy selection				Enterprises	
				Active innovation z	Negative innovation (1-z)
Government	R&D subsidies x	Industrial park	Outward incentives f	R_s-B_{gr} - C_{gl} R_s-B_{ph} - C_{pl} R_s - C_f+B_{gr}	-B_{gr} - C_{gl} -B_{ph} - C_{pl} B_{gr}
			Inward incentives (1-f)	R_e -B_{gr} - C_{gl} R_e - B_{pl} - C_{ph} R_e - C_f + B_{gr} +B_{pl}	-B_{gr} - C_{gl} -B_{pl} - C_{ph} B_{gr} +B_{pl}
	Tax incentives (1-x)	Industrial park	Outward incentives f	R_s - B_{gt} - C_{gh} R_s- B_{ph} - C_{pl} R_s - C_f+B_{gt}	- C_{gh} -B_{ph} - C_{pl} 0
			Inward incentives (1-f)	R_e - B_{gt} - C_{gh} R_e - B_{pl} - C_{ph} R_e - C_f+B_{gt}+B_{pl}	- C_{gh} -B_{pl} - C_{ph} B_{pl}

3.4. Evolutionary stabilization strategy solution

3.4.1. Stabilization strategy of the government

The probability that the government chooses the “R&D subsidies” strategy to stimulate the enterprises to innovate is x and the replication dynamic equation is:

$$F(x)=\frac{dx}{dt}=x\left(U_{gr}-\overline{U_g}\right) \tag{7}$$

The derivative of F(x) with respect to x yields:

$$\frac{d(F(x))}{dx}=(2x-1)\left(B_{gr}-C_{gh}+C_{gl}-zB_{gt}\right) \tag{8}$$

Let $G(z)=B_{gr}-C_{gh}+C_{gl}-zB_{gt}$

According to the stability theorem of the differential equation, if the probability of the government choosing R&D subsidies is to be in a steady state, it must satisfy: $F(x)=0$ and $\frac{d(F(x))}{dx}<0$. Since $\frac{\partial G(z)}{\partial z}<0$, G(z) about z is a decreasing function. Therefore, when $z^*=\frac{B_{gr}-C_{gh}+C_{gl}}{B_{gt}}$, $G(z)=0$, at this time $\frac{d(F(x))}{dx}=0$, the government cannot determine the stabilization strategy; when $z<z^*$, $G(z)>0$, at this time $\frac{d(F(x))}{dx}|_{x=0}<0$, $x=0$ is the Evolutionary Stable Strategy (ESS) of the government; conversely, $x=1$ is the ESS, the phase diagram of the government strategy selection is show in Fig. 2.

Fig. 2 shows that the probability of steadily choosing the “tax incentives” strategy by the government is the volume of A_1 and the probability of choosing the “R&D subsidies” strategy is the volume of A_2 , which is calculated as:

$$V_{A_1}=\int_0^1\int_0^1\frac{B_{gr}-C_{gh}+C_{gl}}{B_{gt}}dxdf=\frac{B_{gr}-C_{gh}+C_{gl}}{B_{gt}} \tag{9}$$

$$V_{A_2}=1-V_{A_1}=1-\frac{B_{gr}-C_{gh}+C_{gl}}{B_{gt}} \tag{10}$$

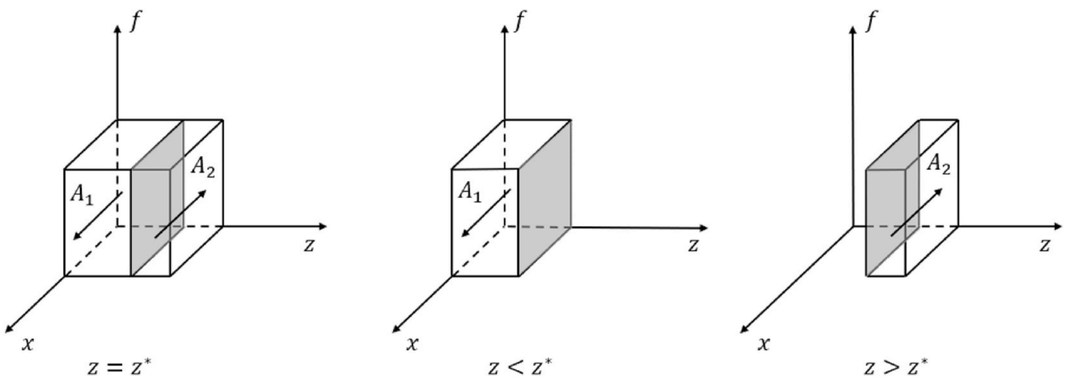

Fig. 2. Phase diagram of the government strategy selection.

Corollary 1. *The probability of choosing the "R&D subsidies" strategy by the government is positively related to the tax incentives* B_{gt} *and the cost of managing the enterprises' innovation* C_{gh} *under the "tax incentives" strategy, and negatively related to the R&D subsidies* B_{gr} *and the cost of managing the enterprises' innovation* C_{gl} *under the "R&D subsidies" strategy.*

Proof. *Based on the expression* V_{A_2} *for the probability of the government choosing the "R&D subsidies" strategy, and taking the first order partial derivative of each element, we can obtain that:* $\frac{\partial V_{A_2}}{\partial B_{gt}} > 0$, $\frac{\partial V_{A_2}}{\partial C_{gh}} > 0$, $\frac{\partial V_{A_2}}{\partial B_{gr}} < 0$, $\frac{\partial V_{A_2}}{\partial C_{gl}} < 0$. *Therefore, either the increase of* B_{gt} *and* C_{gh} *or the decrease of* B_{gr} *and* C_{gl} *can escalate the probability of the government choosing the "R&D subsidies" strategy.*

Corollary 1 suggests that the government's choice between "R&D subsidies" or "tax incentives" to stimulate innovation depends on the relative magnitude of the respective costs (incentives costs and management costs) of the two strategies. In general, the government tends to choose the "R&D subsidies" strategy, because most of the subsidies are direct and ex-ante financial support, and the cost of the government managing enterprises C_{gl} is lower than C_{gh} which stands for the management cost the government choosing the "tax incentives" strategy. But if the incentive cost (R&D subsidy cost) is too high while the tax incentive cost is low, the government tends to choose the "tax incentives" strategy.

3.4.2. Stabilization strategy of the industrial park

The probability that the industrial park chooses the "outward incentives" strategy is f and the replication dynamic equation is:

$$F(f) = \frac{df}{dt} = f\left(U_{ph} - \overline{U_p}\right) \tag{11}$$

The derivative of F(f) with respect to f yields:

$$\frac{dF(f)}{df} = (2f-1)\left(B_{ph} - B_{pl} - C_{ph} + C_{pl} + zR_e - zR_s\right) \tag{12}$$

Let $J(z) = (R_e - R_s)z + B_{ph} - B_{pl} - C_{ph} + C_{pl}$

According to the stability theorem of the differential equation, if the probability of the industrial park choosing the "outward incentives" strategy is to be in a steady state, it must satisfy: $F(f) = 0$ and $\frac{d(F(f)}{df} < 0$. Since $\frac{\partial J(z)}{\partial z} = R_e - R_s > 0$, J(z) about z is an increasing function. Therefore, when $z = \frac{B_{pl}+C_{ph}-B_{ph}-C_{pl}}{R_e-R_s} = z^*$, $J(z) = 0$, at this time $\frac{d(F(f))}{df} \equiv 0$, the industrial park cannot determine the stable strategy; when $z < z^*$, $J(z) < 0$, at this time $\frac{d(F(f))}{df}|_{f=1} > 0$, $f = 1$ is the Evolutionary Stable Strategy (ESS) of the industrial park; conversely, $f = 0$ is the ESS, the phase diagram of the industrial park strategy selection is show in Fig. 3.

Fig. 3 shows that the probability that the industrial park chooses the "outward incentives" strategy is the volume of B_1 and the probability of choosing the "inward incentives" strategy is the volume of B_2, which is calculated respectively as:

$$V_{B_1} = \int_0^1 \int_0^1 \frac{B_{pl} + C_{ph} - B_{ph} - C_{pl}}{R_e - R_s} dxdf = \frac{B_{pl} + C_{ph} - B_{ph} - C_{pl}}{R_e - R_s} \tag{13}$$

$$V_{B_2} = 1 - V_{B_1} = 1 - \frac{B_{pl} + C_{ph} - B_{ph} - C_{pl}}{R_e - R_s} \tag{14}$$

Corollary 2. *The probability of the industrial park choosing the "outward incentives" strategy is positively related to the subsidy* B_{pl}*, the management cost* C_{ph} *and the supportive benefits* R_s*, while negatively related to the subsidy* B_{ph}*, the management cost* C_{pl} *and the additional benefits* R_e*.*

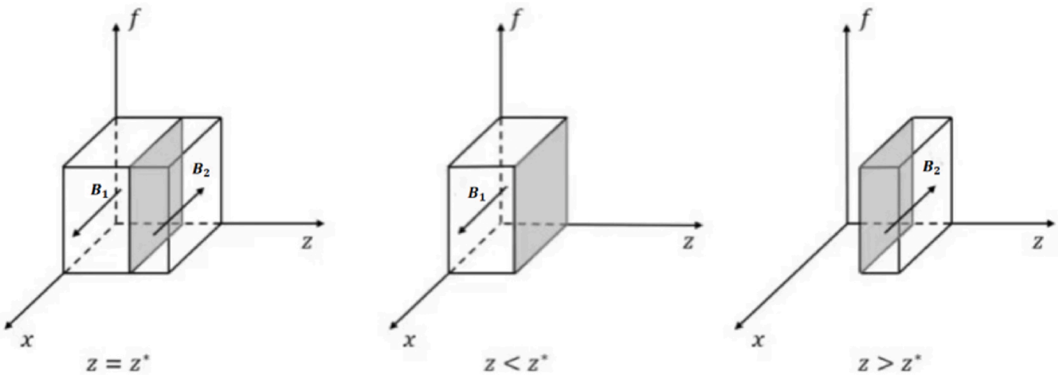

Fig. 3. Phase diagram of the industrial park strategy selection.

Proof. *Based on the expression* V_{B_1} *for the probability of the industrial park choosing the "outward incentives" strategy , and taking the first order partial derivative of each element, we can obtain that:* $\frac{\partial V_{B_1}}{\partial B_{pl}} > 0$, $\frac{\partial V_{B_1}}{\partial C_{ph}} > 0$, $\frac{\partial V_{B_1}}{\partial R_s} > 0$, $\frac{\partial V_{B_1}}{\partial B_{ph}} < 0$, $\frac{\partial V_{B_1}}{\partial C_{pl}} < 0$, $\frac{\partial V_{B_1}}{\partial R_e} < 0$. *Therefore, either the increase of* B_{pl}, C_{ph} *and* R_s *or the decrease of* B_{ph}, C_{pl} *and* R_e *can escalate the probability of the industrial park choosing the "outward incentives" strategy.*

Corollary 2 shows that the strategy choice of the industrial park is not only related to the cost of "outward incentives" strategy and "inward incentives" strategy, but also closely related to the benefits of the two strategies. Under the "inward incentives" strategy, the park's subsidy cost B_{pl} is smaller, the benefits R_e is larger if the enterprises also actively innovate, in this case the park will tend to choose the "inward incentives" strategy. However, the "inward incentives" strategy also means that the park pays more attention to the process of enterprise innovation and has to evaluate and reward the innovation performance, and the management cost C_{ph} is higher. When the C_{ph} is too high, the industrial park may prefer "outward incentives" strategy.

3.4.3. Stabilization strategy of the enterprises

The probability that an enterprise chooses the "active innovation" strategy is z and the replication dynamic equation is:

$$F(z) = \frac{dz}{dt} = z\left(U_{ey} - \overline{U_e}\right) \tag{15}$$

The derivative of F(z) with respect to z yields:

$$\frac{d(F(z))}{dz} = (1 - 2z)\left(B_{gt} - C_f + R_e - fR_e + fR_s - xB_{gt}\right) \tag{16}$$

Let $H(f) = -(R_e - R_s)f - xB_{gt} + B_{gt} - C_f + R_e$

According to the stability theorem of the differential equation, if the probability of an enterprise choosing actively innovate is to be in a steady state, it must satisfy: $F(z) = 0$ and $\frac{d(F(z))}{dz} < 0$. Since $\frac{\partial H(f)}{\partial f} < 0$, H(f) about f is a decreasing function. Therefore, when $f = \frac{-xB_{gt} + B_{gt} - C_f + R_e}{R_e - R_s} = f^*$, $H(f) = 0$, at this time $\frac{d(F(z))}{dz} \equiv 0$, the enterprises cannot determine the stable strategy; when $f < f^*$, $H(f) > 0$, at this time $\left.\frac{d(F(z))}{dz}\right|_{z=1} < 0$, $z = 1$ is the enterprise's Evolutionary Stable Strategy (ESS); conversely, $z = 0$ is the ESS, the phase diagram of enterprises strategy selection is show in Fig. 4.

Fig. 4 shows that the probability that an enterprise actively innovates is the volume of C_1 and the stable probability of negative innovation is the volume of C_2, which is calculated as:

$$V_{C_1} = \int_0^1 \int_{f_1}^{f_2} \frac{-xB_{gt} + B_{gt} - C_f + R_e}{R_e - R_s} \mathrm{d}x\mathrm{d}z = \frac{R_e - R_s}{2B_{gt}} \tag{17}$$

$$V_{C_2} = 1 - V_{C_1} \tag{18}$$

Where $f_1 = \frac{B_{gt} + R_s - C_f}{B_{gt}}$, $f_2 = \frac{B_{gt} + R_e - C_f}{B_{gt}}$ (obtained from $0 \le \frac{-xB_{gt} + B_{gt} - C_f + R_e}{R_e - R_s} \le 1$).

Corollary 3. *The stable probability of an enterprise choosing the "active innovation" strategy is positively related to the additional benefits* R_e*, and negatively related to the supportive benefits* R_s *and the tax incentives* B_{gt} *provided by the government.*

Proof. *Based on the expression* V_{C_1} *for the probability of the enterprises choosing the "active innovation" strategy, and taking the first order partial derivative of each element, we can obtain that:* $\frac{\partial V_{C_1}}{\partial R_e} > 0$, $\frac{\partial V_{C_1}}{\partial R_s} > 0$, *and* $\frac{\partial V_{C_1}}{\partial B_{gt}} < 0$. *Therefore, whether the increase of* R_e *or the decrease of*

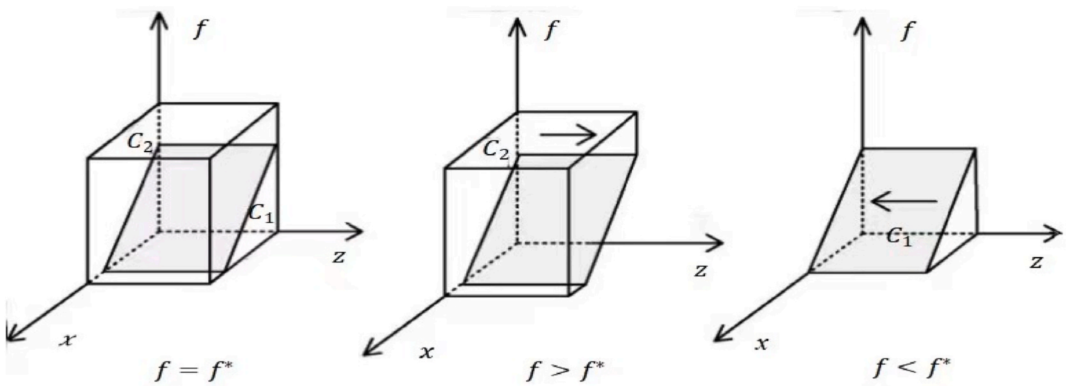

Fig. 4. Phase diagram of enterprises strategy selection.

R_s and B_{gt} can escalate the probability of the enterprises choosing the "active innovation" strategy.

Corollary 3 shows that the strategy choice of the enterprises is influenced by the strategy choice of the park and the government. When the park chooses the "inward incentives" strategy, the additional benefits brought to enterprises, such as optimized business environment and increased stickiness of cooperation, will enhance the enthusiasm of enterprises to innovate. However, when the government chooses the "tax incentives" strategy to stimulate innovation, the difficulties for the enterprises completing the assessment to obtain tax incentives will inhibit the enthusiasm of the enterprises to innovate.

3.4.4. Stability analysis of the equilibrium points

From $F(x)=0$, $F(f)=0$, $F(z)=0$, the system equilibrium point can be obtained as: $E_1(0,0,0)$, $E_2(1,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$, $E_5(1,1,0)$, $E_6(1,0,1)$, $E_7(1,1,0)$, $E_8(1,1,1)$. The Jacobian matrix of the three-party evolutionary game system is:

$$J=\begin{bmatrix} J_1 & J_2 & J_3 \\ J_3 & J_4 & J_5 \\ J_6 & J_7 & J_8 \end{bmatrix}=\begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial f} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(f)}{\partial x} & \frac{\partial F(f)}{\partial f} & \frac{\partial F(f)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial f} & \frac{\partial F(z)}{\partial z} \end{bmatrix}$$

$$=\begin{bmatrix} (2x-1)\left(B_{gr}-C_{gh}+C_{gl}-zB_{gt}\right) & 0 & x(1-x)B_{gt} \\ 0 & (2f-1)\left(B_{ph}-B_{pl}-C_{ph}+C_{pl}+zR_e-zR_s\right) & f(f-1)(R_e-R_s) \\ z(z-1)B_{gt} & z(z-1)(R_e-R_s) & (1-2z)\left(B_{gt}-C_f+R_e-fR_e+fR_s-xB_{gt}\right) \end{bmatrix}$$

Using Lyapunov's first method: the equilibrium point is asymptotically stable if all the eigenvalues of the Jacobi matrix have negative real parts; the equilibrium point is unstable if at least one of the eigenvalues of the Jacobi matrix has positive real parts; the equilibrium point is in a critical state if all the eigenvalues of the Jacobi matrix have negative real parts except for the eigenvalues with zero real parts, while the stability cannot be determined by the eigenvalues sign. The stability of each equilibrium point is analyzed, as shown in Table 3.

Corollary 4. *When $C_f < R_e$, $B_{pl}-B_{ph}+C_{ph}-C_{pl} < R_e-R_s$, there exists a stability point $E_6(1,0,1)$ for the replicated dynamical system.*

Corollary 4 shows that when the cost of active innovation is less than the additional benefits under the "inward incentives" strategy, and the cost difference between "inward incentives" strategy and "outward incentives" strategy is less than the benefits difference yielded by the two strategies, the park chooses the "inward incentives" strategy, which can not only encourage the enterprises to innovate, but also bring benefits to the park itself, and the combined strategy evolves and stabilizes at (R&D subsidies, inward incentives, active innovation).

Corollary 5. *When $C_f < R_s$, $B_{pl}-B_{ph}+C_{ph}-C_{pl} > R_e-R_s$, there exists a stability point $E_8(1,1,1)$ for the replicated dynamical system.*

Corollary 5 shows that when the cost of active innovation is less than the supportive benefits under "outward incentives" strategy and the cost difference between "inward incentives" strategy and "outward incentives" strategy is more than the benefits difference yielded by the two strategies, the park chooses the "outward incentives" strategy, which is more beneficial to the park's innovation and development, and the combined strategy evolves and stabilizes at (R&D subsidies, outward incentives, active innovation).

Table 3
Equilibrium points stability analysis.

Equilibrium points	Jacobian matrix eigenvalues		Stability conclusion	Conditions
	$\lambda_1,\lambda_2,\lambda_3$	Real part symbol		
$E_1(0,0,0)$	$B_{gt}-C_f+R_e$, $C_{gh}-B_{gr}-C_{gl}$, $B_{pl}-B_{ph}+C_{ph}-C_{pl}$	(+ , − , +)	Instability point	\
$E_2(1,0,0)$	R_e-C_f, $B_{gr}-C_{gh}+C_{gl}$, $B_{pl}-B_{ph}+C_{ph}-C_{pl}$	(× , + , +)	Instability point	\
$E_3(0,1,0)$	$B_{gt}-C_f+R_s$, $C_{gh}-B_{gr}-C_{gl}$, $B_{ph}-B_{pl}-C_{ph}+C_{pl}$	(+ , − , −)	Instability point	\
$E_4(0,0,1)$	$C_f-B_{gt}-R_e$, $B_{gt}-B_{gr}+C_{gh}-C_{gl}$, $B_{pl}-B_{ph}+C_{ph}-C_{pl}-R_e+R_s$	(− , + , ×)	Instability point	\
$E_5(1,1,0)$	R_s-C_f, $B_{gr}-C_{gh}+C_{gl}$, $B_{ph}-B_{pl}-C_{ph}+C_{pl}$	(× , + , −)	Instability point	\
$E_6(1,0,1)$	C_f-R_e, $B_{gr}-B_{gt}-C_{gh}+C_{gl}$, $B_{pl}-B_{ph}+C_{ph}-C_{pl}-R_e+R_s$	(× , − , ×)	ESS	①
$E_7(0,1,1)$	$C_f-B_{gt}-R_s$, $B_{gt}-B_{gr}+C_{gh}-C_{gl}$, $B_{ph}-B_{pl}-C_{ph}+C_{pl}+R_e-R_s$	(− , + , ×)	Instability point	\
$E_8(1,1,1)$	C_f-R_s, $B_{gr}-B_{gt}-C_{gh}+C_{gl}$, $B_{ph}-B_{pl}-C_{ph}+C_{pl}+R_e-R_s$	(× , − , ×)	ESS	②

Notes: × indicates that the symbol is uncertain; ① $C_f < R_e, B_{pl}-B_{ph}+C_{ph}-C_{pl} < R_e-R_s$; ② $C_f < R_s$, $B_{pl}-B_{ph}+C_{ph}-C_{pl} > R_e-R_s$.

4. Numerical simulations

4.1. The stable game strategies of the three parties

In order to verify the factors influencing the probability of each party's strategy, the model is numerically assigned with the realistic situation and simulated using Matlab software.

4.1.1. The effect of government's strategy choice on the evolutionary game

The relationship between the probability of the government choosing the "R&D subsidies" strategy and B_{gt}, C_{gh}, B_{gr}, C_{gl} is analyzed by drawing a diagram. From equation $V_{A_2} = 1 - \frac{B_{gr} - C_{gh} + C_{gl}}{B_{gt}}$, for the convenience of graphing, let $\delta = B_{gr} - C_{gh} + C_{gl}$, then V_{A_2} can become $V_{A_2} = 1 - \frac{\delta}{B_{gt}}$. Since $B_{gr} - C_{gh} + C_{gl} > 0$ (obtained from $0 < \frac{B_{gr} - C_{gh} + C_{gl}}{B_{gt}} < 1$), so assumes that $\delta \in [5, 10]$, $B_{gt} \in [10, 40]$.

Substituting the values, we can obtain the probability relationship diagram shown in Fig. 5.

From Fig. 5, it can be seen that when δ is smaller (indicating that the cost associated with the government's choice of R&D subsidies is smaller) and the government gives higher tax incentives to enterprises, the government tends to choose the "R&D subsidies" strategy; and vice versa the government tends to choose the "tax incentives" strategy.

4.1.2. The effect of industrial parks' strategy choice on the evolutionary game

The relationship between the probability of industrial parks choosing the "outward incentives" strategy and B_{pl}, C_{pl}, B_{ph}, C_{ph}, R_e, R_s is analyzed by drawing a diagram. From equation $V_{B_1} = \frac{(B_{pl} + C_{ph}) - (B_{ph} + C_{pl})}{R_e - R_s}$, for the sake of drawing, let $\alpha = (B_{pl} + C_{ph}) - (B_{ph} + C_{pl})$ and $\beta = R_e - R_s$, then V_{B_1} can be transformed into $V_{B_1} = \frac{\alpha}{\beta}$. Since $R_e > R_s$, $B_{pl} + C_{ph} > B_{ph} + C_{pl}$, then $\alpha > 0, \beta > 0$, and we assume that $\alpha \in [5, 10]$, $\beta \in [5, 30]$.

Substituting the values, we can obtain the probability relationship diagram shown in Fig. 6.

From Fig. 6, when the difference between the "inward incentives" strategy and "outward incentives" strategy on the cost of industrial park's incenting and managing the enterprises is low, as well as the difference between additional benefits and supportive benefits is high, the industrial park cannot obtain larger benefits from the "outward incentives" strategy and tends to choose the "inward incentives" strategy. On the contrary, the industrial park tends to choose the "outward incentives" strategy.

4.1.3. The effect of enterprises' strategy choice on the evolutionary game

The relationship between the enterprises' active innovation and R_e, R_s, B_{gt} is analyzed by drawing a diagram. From the equation $V_{C_1} = \frac{R_e - R_s}{2B_{gt}}$, for the sake of drawing, let $\beta = R_e - R_s$, then V_{C_1} can be transformed into $V_{C_1} = \frac{\beta}{B_{gt}}$. Since $R_e > R_s$, we assume that $\beta \in [5, 30]$, $B_{gt} \in [10, 40]$. Substituting the values, we obtain the probability relationship diagram shown in Fig. 7.

As shown in Fig. 7, when the difference between additional benefits and supportive benefits is low, as well as the tax incentives provided by the government are high, the enterprises do not tend to actively innovate; conversely, they tend to choose the "active innovation" strategy.

4.2. The effect of variables on the evolutionary game

In order to verify the validity of the evolutionary stability analysis, the model is assigned with numerical values in combination with the realistic situation. Then the simulation analysis is performed by using Matlab software. According to the previous analysis, the following assignments are made to obtain the array I: $R_e = 40$, $R_s = 10$, $C_f = 35$, $B_{ph} = 10$, $B_{pl} = 5$, $C_{pl} = 10$, $C_{ph} = 40$, $B_{gr} = 20$,

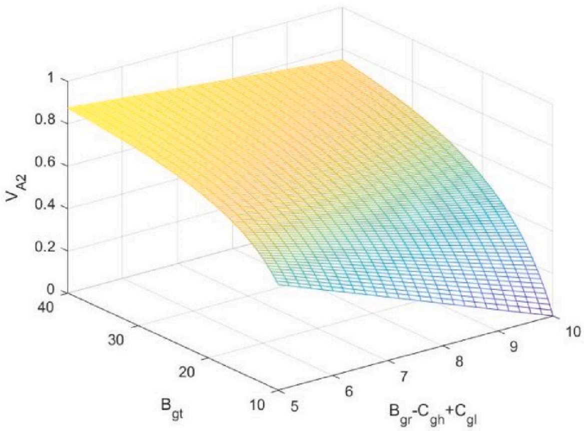

Fig. 5. Relationship between the probability of the government choosing the "R&D subsidies" strategy and B_{gt}, C_{gh}, B_{gr}, C_{gl}.

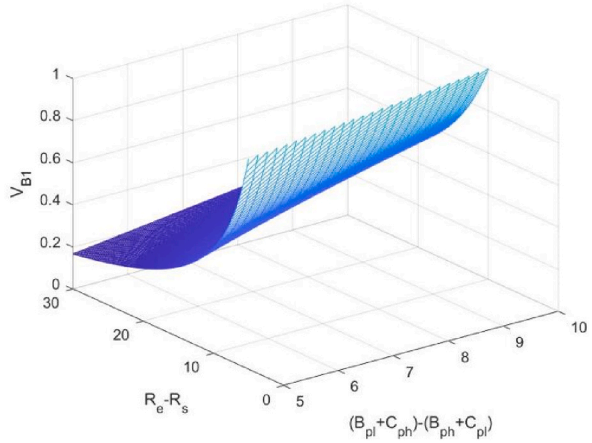

Fig. 6. The relationship between the probability of the industrial park choosing the "outward incentives" strategy and $\alpha = (B_{pl} + C_{ph}) - (B_{ph} + C_{pl})$ and $\beta = R_e - R_s$.

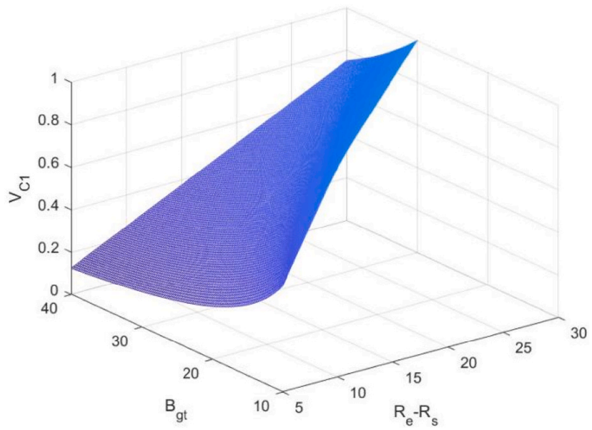

Fig. 7. The relationship between the probability of the enterprises choosing the "active innovation" strategy and $\beta = R_e - R_s, B_{gt}$.

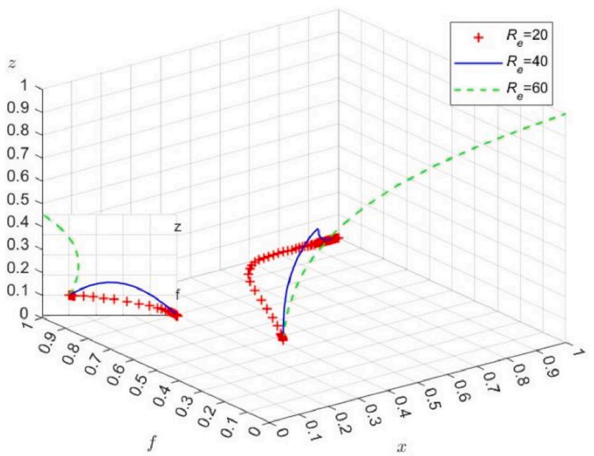

Fig. 8. Simulation results of changing R_e.

$B_{gt} = 20, C_{gl} = 10$, $C_{gh} = 40$. On this basis, we analyze their influence on the process and outcome of the evolutionary game.

(1) The additional benefits R_e. For analyzing the effect of the change in R_e on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $R_e = 20$, 40, 60, are shown in Fig. 8.

From Fig. 8, the final stabilization point of the system evolution varies with the increase of additional benefits such as optimization of the business environment and enhancement of cooperation stickiness when the enterprises actively innovate and the park chooses the "inward incentives" strategy. When R_e is smaller, industrial parks tend to choose the "outward incentives" strategy, because the benefits they can obtain through "inward incentives" strategy are smaller. Under the "outward incentives" strategy, the park focuses on attracting high-quality external innovation, thereout, the park lacks innovation incentives and management for enterprises, and the enterprises tend to make negative innovation. With the increase of R_e, the industrial parks tend to choose the "inward incentives" strategy to improve their own revenue. Along with the enhancement of the park's attention to enterprise innovation, the enterprises are also more likely to innovate actively.

(2) The supporting earnings R_s. For analyzing the effect of the change in R_s on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $R_s = 0, 20, 40$, are shown in Fig. 9.

From Fig. 9, the final stabilization point of the system evolution differs with the increasement of the supportive benefits R_s which is generated in the process of innovation. In this instance, the enterprises integrate resources to innovate actively, while the park chooses the "outward incentives" strategy. When R_s is smaller, the industrial park tends to choose the "inward incentives" strategy, because the benefits they can obtain through the "outward incentives" strategy are smaller. Under the "inward incentives" strategy, the park pays more attention to the process of enterprises innovation and evaluates the innovation performance, so the enthusiasm of the enterprises to innovate is higher; As the R_s increases, the industrial park tends to choose the "outward incentives" strategy to improve its own revenue.

(3) The costs C_f associated with the enterprises' active innovation. For analyzing the effect of the change in C_f on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $C_f = 10, 40, 60$, are shown in Fig. 10.

From Fig. 10, the final stabilization point of system evolution differs with the increasement of the associated cost C_f paid by enterprises to innovate actively. When the cost is smaller, the innovation enthusiasm of the enterprises is higher, and the park prefers to encourage interior enterprises to maintain active innovation, instead of investing money to compete for limited external innovation resources. Then the industrial parks and the enterprises can achieve a win-win situation. When the cost is higher, the innovation enthusiasm of the enterprises to innovate decreases obviously, and the industrial park will be more inclined to choose the "outward incentives" strategy to promote innovation.

(4) The costs C_{pl} of managing enterprises innovation when the park choosing the "outward incentives" strategy. For analyzing the effect of the change in C_{pl} on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $C_{pl} = 0, 20, 40$, are shown in Fig. 11.

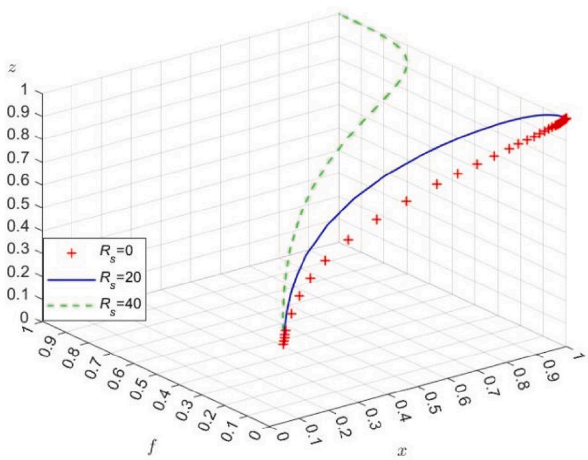

Fig. 9. Simulation results of changing R_s.

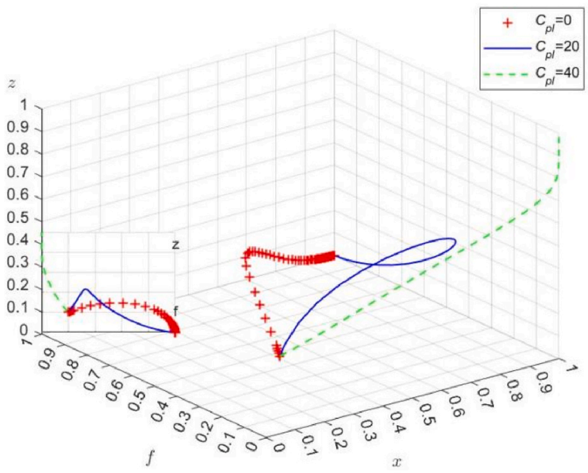

Fig. 10. Simulation results of changing C_f.

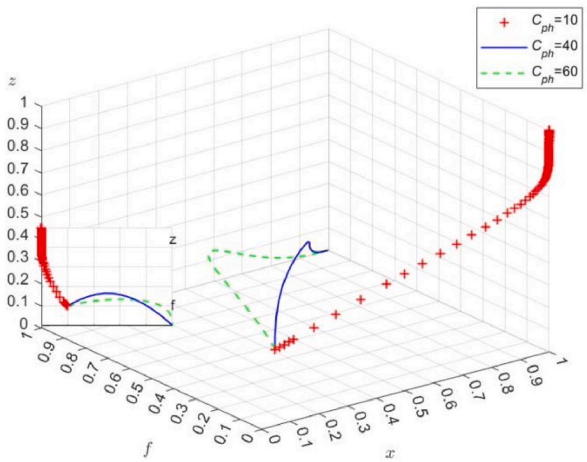

Fig. 11. Simulation results of changing C_{pl}.

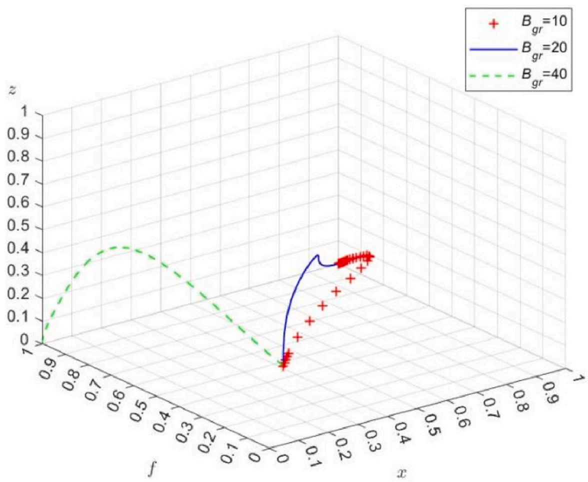

Fig. 12. Simulation results of changing C_{ph}.

From Fig. 11, the final stabilization point of system evolution differs with the increasement of the cost C_{pl} of managing enterprises innovation when the park chooses the “outward incentives” strategy. When C_{pl} is smaller, the industrial park tends to choose the “outward incentives” strategy. In this case, the focus of the park is not to promote the enterprises to innovate, so the motivation of enterprise innovation is lower. When C_{pl} is larger, the industrial park tends to choose the “inward incentives” strategy to reduce its own management cost, and the innovation enthusiasm of the enterprises is higher.

(5) The costs C_{ph} of managing enterprises innovation when the park chooses the “inward incentives” strategy. For analyzing the effect of the change in C_{ph} on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $C_{ph} = 10, 40, 60$, are shown in Fig. 12.

From Fig. 12, the final stabilization point of system evolution varies with the increasement of the cost C_{ph} of managing enterprise innovation when the park chooses the “inward incentives” strategy. When C_{ph} is smaller, the industrial park tends to choose the “inward incentives” strategy. In this case, the park focuses on inwardly promoting enterprises innovation, so the enthusiasm of the enterprises to innovate is higher. When C_{ph} is larger, the industrial park tends to choose the “outward incentives” strategy to reduce its own management cost, and the innovation enthusiasm of the enterprises is lower.

(6) Government’s R&D subsidies B_{gr}. For analyzing the effect of the change in B_{gr} on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $B_{gr} = 10, 20, 40$, are shown in Fig. 13.

From Fig. 13, it can be seen that the final stabilization point of system evolution varies with the increasement of the R&D subsidies B_{gr}. When B_{gr} is smaller, the government tends to choose the “R&D subsidies” strategy; when B_{gr} is larger, the government tends to choose the “tax incentives” strategy in order to reduce its own incentive cost.

(7) Government’s tax incentives B_{gt}. For analyzing the effect of the change in B_{gt} on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $B_{gt} = 10, 20, 40$, are shown in Fig. 14.

From Fig. 14, the final stabilization point of the system evolution remains the same regardless of the change of the tax incentives B_{gt}. The possible reason is that the probability $V_{A_2} = 1 - \frac{B_{gr} - C_{gh} + C_{gl}}{B_{gt}}$ of the government choosing the “R&D subsidies” strategy shows that the tax incentives have less influence on the government’s strategy choice, which is due to the nature of the tax incentives as well as the nature and the size of the enterprises. First, the tax incentives belong to ex-post support and the enterprises need to complete the government’s target assessment to obtain tax incentives, which is difficult for many enterprises; second, the tax incentives have a more significant impact on innovation of large-scale enterprises, while R&D subsidies play a more significant role in promoting innovation of small and medium-sized enterprises. Therefore, the government generally prefers the “R&D subsidies” strategy.

(8) The costs C_{gl} of managing enterprises innovation when the government chooses the “R&D subsidies” strategy. For analyzing the effect of the change in C_{gl} on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $C_{gl} = 0, 20, 40$, are shown in Fig. 15.

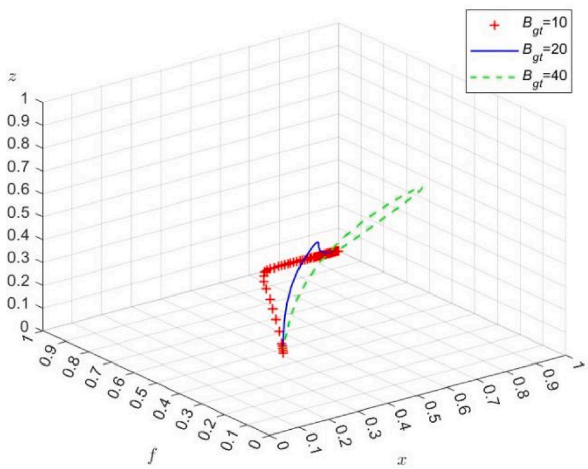

Fig. 13. Simulation results of changing B_{gr}.

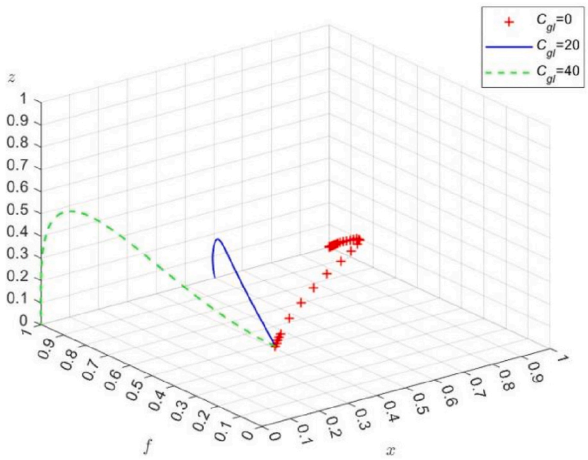

Fig. 14. Simulation results of changing B_{gt}.

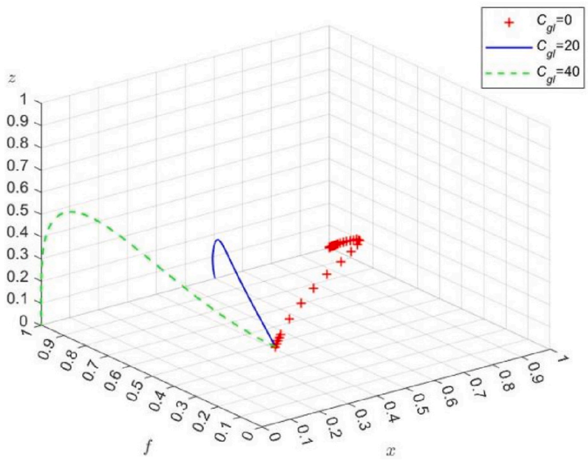

Fig. 15. Simulation results of changing C_{gl}.

From Fig. 15, it can be seen that the final stabilization point of the system evolution differs with the increasement of the cost C_{gl} when the government chooses the "R&D subsidies" strategy. When C_{gl} is smaller, the government tends to choose the "R&D subsidies" strategy; when C_{gl} is larger, the government tends to choose the "tax incentives" strategy to reduce its own management cost.

(9) The costs C_{gh} of managing enterprises innovation when the government chooses the "tax incentives" strategy. For analyzing the effect of the change in C_{gh} on the process and outcome of the evolutionary game, the simulation results of the replicated dynamic equations evolving 50 times by respectively assigning $C_{gh} = 10, 40, 60$, are shown in Fig. 16.

From Fig. 16, it can be seen that the final stabilization point of the system evolution differs with the increasement of the costs C_{gh} when the government chooses the "tax incentives" strategy. When C_{gh} is smaller, the government tends to choose the "tax incentives" strategy; when it is larger, the government tends to choose the "R&D subsidies" strategy to reduce its own management cost.

After analyzing the influence of each individual indicator on the evolutionary process and outcome of the three parties of the game, the following assignments and evolutions are made to verify the stability analysis of the equilibrium point.

Array 1 satisfies condition ① in Corollary 4. Assign to array 2: $R_e = 40$, $R_s = 30$, $C_f = 10$, $B_{ph} = 10$, $B_{pl} = 5$, $C_{pl} = 10$, $C_{ph} = 40$, $B_{gr} = 20$, $B_{gt} = 20$, $C_{gl} = 10$, $C_{gh} = 40$, satisfying the condition ② in Corollary 5, the two sets of values are evolved 50 times from different initial strategy combinations, and the results are shown in Figs. 17 and 18 respectively.

From Fig. 17, it can be seen that there is only one evolutionary stable strategy combination (R&D subsidies, inward incentives, active innovation) of the system at this time, which is consistent with the conclusion of Corollary 4. Fig. 18 shows that the evolutionary stability point of the system is (1, 1, 1), i.e. (R&D subsidies, outward incentives, active innovation) when the condition ② in Table 3 is satisfied, which is consistent with Corollary 5.

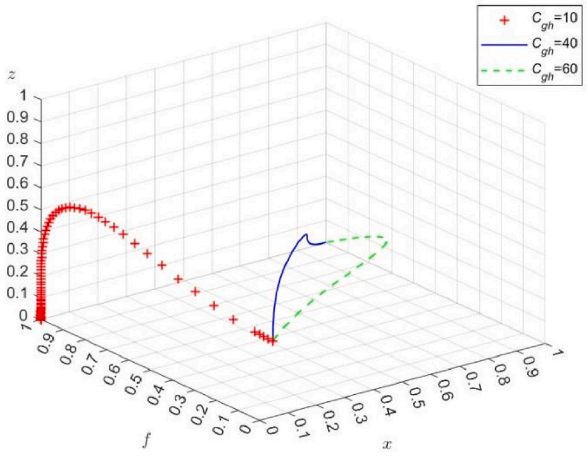

Fig. 16. Simulation results of changing C_{gh}.

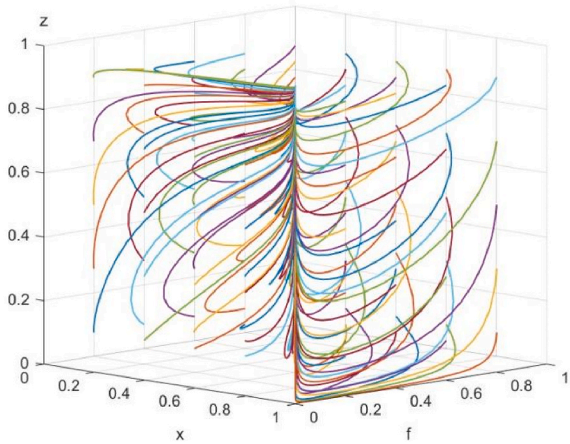

Fig. 17. Result of 50 times evolution of array 1.

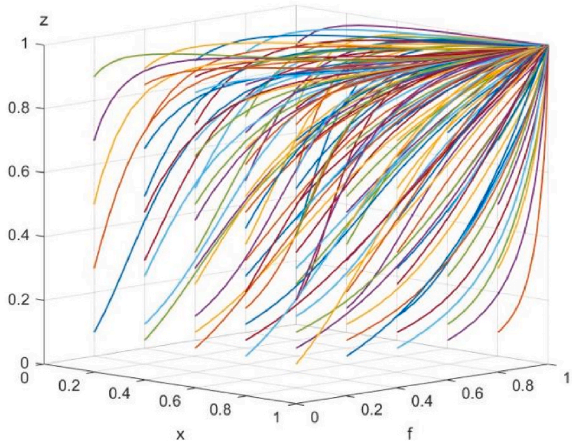

Fig. 18. Result of 50 times evolution of array 2.

5. Conclusions and managerial insights

5.1. Conclusions

Considering the high-quality development of the industrial parks, this study constructed a triple evolutionary game model between government, industrial parks and enterprises. Through solving the model, we obtained the trivial solution between the innovation willingness of the enterprises in the park, the policy preference of the government, and the support orientation of the parks. The main conclusions are as follows.

(1) The government's policy preference depends on the incentive and management costs of "R&D subsidies" or "tax incentives". Since most of the R&D subsidies belong to direct and ex-ante financial support, the government's cost of the innovation management on enterprises is lower in this situation, and the government tends to choose the "R&D subsidies" strategy. Conversely, tax incentives belong to indirect and ex-post financial support, and the government needs to evaluate and reward the enterprises' innovation performance, thus the cost of innovation management on enterprises is relatively high. However, if the cost of R&D subsidies is higher in this case, the government will prefer the "tax incentives" strategy.

(2) The industrial park's support orientation not only depends on the incentive and management cost caused by each strategy, but also closely relates to the benefits brought by the strategies. If the industrial park chooses the "inward incentives" strategy, it will pay more attention to the innovation of enterprises, and the enterprises will be more inclined to "active innovation". In this case, additional benefits such as greater business environment optimization and enhanced cooperation stickiness can be generated. When the enterprises innovate actively and achieve better innovation performance, the park will also be more inclined to choose the "inward incentives" strategy and to encourage the enterprises to maintain active innovation. However, the industrial park's attention to the innovation process of enterprises will also lead to high management costs. While, when the cost is too high and the park pays more attention of innovation resources from outside, the industrial park tends to choose the "outward incentives" strategy.

(3) The enterprise's innovation willingness is influenced by the choice of both the industrial parks and the government. When the park chooses the "inward incentives" strategy, the above-mentioned additional benefits for enterprises will enhance their enthusiasm to innovate, and the enterprises tend to choose the "active innovation" strategy. At this point, if the costs difference between the "inward incentives" strategy and the "outward incentives" strategy is smaller than the benefits difference between the two types of strategies, the strategy combination of the game among the government, the industrial park and the enterprises will be stabilized at (R&D subsidies, inward incentives, active innovation). When the costs difference between the two strategies is greater than the benefits difference, the strategy combination of the game will be stable at (R&D subsidies, outward incentives, active innovation). But, when the government chooses the "tax incentives" strategy, it has to assess the innovation performance of the enterprises with corresponding indexes, and if the enterprises fail to meet the requirements, they will not get the incentives, which will inhibit their enthusiasm to innovate, and lead them to adopt the "negative innovation" strategy.

5.2. Theoretical insights

This paper studies the enterprise innovation under the three-party game, which is an in-depth analysis of the innovation process on the basis of the inter-organizational cooperation theory and the synergy theory. Although this paper adopts the evolutionary game method, it is generally oriented to the win-win situation of all parties. Specifically, this paper is conducive to expanding relevant theoretical understanding in the following three aspects:

Firstly, in the theory of innovation, more attention should be paid to the behavioral interaction among multiple subjects. The industrial parks are the "habitat" for the innovation, forming an innovation ecosystem of interdependence and symbiotic evolution among different organizations and support systems around the leading industry [8,16]. This paper makes a framework analysis of the innovation process of the system, especially elaborates the strategy selection of each innovation subject in the game based on the actual innovation experience, which can provide ideas for the deepening of innovation theory from the perspective of subject behavior.

Secondly, the behavior of innovation subjects is characterized by uncertainty, so the game process among them should be viewed objectively and optimized. Governments, industrial parks and enterprises have different functions and behavioral goals [3–5,17,25], and in the process of innovation interaction, each subject will constantly adjust its specific behavior according to the strategic choices of other subjects. From the perspective of sustainable development, we should respect the uncertainty of each subject's behavior and expand the theory of innovation ecosystem based on evolutionary game.

Thirdly, the enterprise innovation in industrial parks is a process of value co-creation, and the theory of innovation system should be improved at the institutional and governance levels [20,29,33]. The current innovation system theory mainly focuses on the relevant research at the national, regional, alliance and enterprise levels [7,19,38], while this paper takes the industrial park as a specific research object, forming an important branch of the park innovation system research, conducive to enriching the content of the innovation system theory from the institutional and governance levels.

5.3. Managerial insights

Based on the previous conclusions, this study puts forward the following countermeasures and suggestions.

First, when setting innovation incentive policies, the government should first formulate scientific and reasonable R&D subsidy policies. Compared with ex-post tax incentives, R&D subsidies can more effectively stimulate enterprises' innovation enthusiasm. Excessive tax incentives may not necessarily promote enterprises to innovate actively, it is likely that the conditions set by the government for the enterprises obtaining tax incentives are too high, and the enterprises cannot enjoy the corresponding tax incentives due to the difficulty of completing the assessment of the requirements, and their innovation enthusiasm will be negatively affected.

Furthermore, the industrial park should pay more attention to the "inward incentives" approach and emphasize the dominant position of enterprises in innovation, which helps to enhance the enthusiasm of enterprises in innovation, so that it can more effectively promote the high-quality development of the innovation system in industrial park. It is worth noting that the "outward incentives" strategy does not have an impact on the enterprises' innovation decisions.

Finally, the enterprises should focus on reducing the costs incurred in the process of active innovation. On the one hand, the lower innovation costs will help increase the enterprises' motivation to innovate and thus promote their continuous innovation activities. On the other hand, the industrial park tends to adopt the "inward incentives" strategy in this situation, which not only enables the enterprises to directly obtain more innovation funds, but also helps to form a good interaction mechanism between the enterprises and the industrial parks, thus promoting a win-win situation.

5.4. *Future research*

Although the research of this study is of certain significance, there are still some limitations for further future studies. First, although this paper considers the key game players in the industrial park's innovation system and selects the government, the industrial park and the enterprises as the game players to build the evolutionary game model, the park innovation system is a complex system [55], and the researchers can further consider adding different participating subjects such as intermediary service agencies and financial institutions in the future. Second, this paper does not further distinguish between the attributes of the enterprises, nor the sizes of them, thus it does not consider the differences in the innovation incentives provided by the government and the industrial parks for enterprises with different attributes and sizes. The future research can refine the analysis of the game strategies of different types of enterprises, and further investigate whether the innovation incentive policies of the government and the industrial park have differentiated policy effects on different types of enterprises.

Funding statement

This study is supported by the National Social Science Foundation of China (21BJY159), and Shanghai 2023 "Science and Technology Innovation Action Plan" Soft Science Research Program (23692104800).

Additional information

No additional information is available for this paper.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Jie Zhen: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Conceptualization. **Juan Ouyang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Conceptualization. **Lan Wang:** Writing – original draft, Validation, Software, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] S.-C. Pan, T.-S. Hu, J.-X. You, S.-L. Chang, Characteristics and influencing factors of economic resilience in industrial parks, Heliyon 9 (4) (2023) e14812.
[2] Y. Xiong, S.S. Li, Can the establishment of university science and technology parks promote urban innovation? Evidence from China, Sustainability 14 (17) (2022) 10707.
[3] J. Zhen, H. Ren, K. Tang, Sustainable development of industrial parks in China: process, morphology, and logic, Urban Plan Forum (1) (2022) 66–73.
[4] A. Liao, Y. Lu, P. L., Research on the selection of government R&D subsidy strategy under leading enterprise-driven cluster, Chinese J, Manag. Sci. (5) (2021) 1–10.
[5] W.J. Li, Y. Zhang, Y.Y. Wu, X. Han, B.H. Guo, G. Xie, Enterprise reciprocity and risk preferences and the sustainable cooperation of innovation activities in industrial parks, Sustainability 13 (17) (2021) 9639.
[6] R. Huggins, A. Johnston, P. Thompson, Network capital, social capital and knowledge flow: how the nature of inter-organizational networks impacts on innovation, Ind. Innovat. 19 (3) (2012) 203–232.

[7] S. Pekkarinen, V. Harmaakorpi, Building regional innovation networks: the definition of an age business core process in a regional innovation system, Reg. Stud. 40 (4) (2006) 401–413.
[8] M.R. Yan, K.M. Chien, L.Y. Hong, T.N. Yang, Evaluating the collaborative ecosystem for an innovation-driven economy: a systems analysis and case study of science parks, Sustainability 10 (3) (2018) 887.
[9] R. Taddeo, A. Simboli, G. Ioppolo, A. Morgante, Industrial symbiosis, networking and innovation: the potential role of innovation poles, Sustainability 9 (2) (2017) 169.
[10] Z.Y. Li, Function analysis of high-tech industry development zone in China, R D Manag. (2) (1991) 20–24.
[11] S.Z. Gu, A strategic approach to the development of China's science & technology parks, China Soft Science (7) (2000) 37–42.
[12] Y.S. Chen, Z.L. Ouyang, R.A. Lu, The design of evaluation index system of NHTZs, Sci. Res. Manag. (6) (1996) 1–7.
[13] W.M. Xu, Technological policy, development zones and TFP of High-Tech enterprises: evidencefrom Shanghai, China Soft Science (10) (2008) 141–147.
[14] G.Q. Yan, H.S. Zhong, J.X. Ren, Q. Sun, Exploration of governing mode of development zone of China, Journal of Management World (1) (2006) 147–148.
[15] J.P. Xie, L.C. Kong, Circular economy and eco-industrial parks: ideas and practices, Journal of Management World (2) (2005) 152–153.
[16] G. Jucevicius, K. Grumadaite, Smart development of innovation ecosystem, Procedia -Social and Behavioral Sciences 156 (4) (2014) 125–129.
[17] J. Yan, J.M. Wang, L.Y. Wang, Research on the innovation efficiency and its influencing factors of urban high-tech industrial parks: a case study of Zhongguancun technology park in Beijing, Urban Development Studies (9) (2020) 132–140.
[18] E.J. Altman, M. Tushman, Platforms, Open/User Innovation, and Ecosystems: A Strategic Leadership Perspective, Social Science Electronic Publishing, 2017.
[19] Y. Wang, Y.Y. Ge, G.F. Yi, Resarch on the development mechanism of the sysbiotic innovation network of the future science city: a case study based on the future science cities, Forum on Science and Technology in China 10 (2022) 104–115.
[20] J.F. Wang, M.Y. Nie, Y.T. Zhang, Study on governance mechanism of science and technology park symbiotic network, Science and Technology Management Research 37 (13) (2017) 130–137.
[21] S. Zygiaris, Smart city reference model: assisting planners to conceptualize the building of smart city innovation ecosystems, Journal of the Knowledge Economy 4 (2) (2013) 217–231.
[22] L. Lecluyse, M. Knockaert, A. Spithoven, The contribution of science parks: a literature review and future research agenda, J. Technol. Tran. 44 (2) (2019) 559–595.
[23] G.A.F. Barrera, X.G.I. Durany, J.R. Pons, J.G.G. Erazo, Trends in global research on industrial parks: a bibliometric analysis from 1996-2019, Heliyon 7 (8) (2021) e07778, 1-14.
[24] Y. Liu, M. Zheng, G. Ren, Evolutionary game between government and enterprises in regional innovation network, Technol. Econ. 35 (7) (2016) 6–11+45.
[25] R.G. Fan, Y.T. Wang, F.Z. Chen, K. Du, Y.Y. Wang, How do government policies affect the diffusion of green innovation among peer enterprises?-an evolutionary-game model in complex networks, J. Clean. Prod. 364 (2022) 132711.
[26] R. Rothwell, W. Zegveld, Reindustrialization and Technology Longman RTI, Research Triangle Institute) International, London, England, 1985, pp. 27–45.
[27] B.H. Hall, The financing of research and development, Oxf. Rev. Econ. Pol. 18 (1) (2002) 35–51.
[28] X. Bai, Y. Wang, X. Su, R&D subsidies or tax incentives: an empirical analysis of government intervention on enterprise innovation performance and innovation quality, Sci. Res. Manag. 40 (6) (2019) 9–18.
[29] L. Pang, J. Guan, The effects of government financial policies on high-tech firm's innovation and growth, Stud. Sci. Sci. 36 (12) (2018) 2259–2269.
[30] J. Blanes, I. Busom, Who participates in R&D subsidy programs? The case of Spanish manufacturing firms, Res. Pol. 33 (10) (2004) 1459–1476.
[31] B. Cassiman, G. Valentini, Open innovation: are inbound and outbound knowledge flows really complementary? Strat. Manag. J. 37 (6) (2016) 1034–1046.
[32] D.R. Shaw, T. Allen, Studying innovation ecosystems using ecology theory, Technol. Forecast. Soc. Change 136 (2018) 88–102.
[33] A. Howell, Agglomeration, absorptive capacity and knowledge governance: implications for public-private firm innovation in China, Reg. Stud. 54 (8) (2020) 1069–1083.
[34] A. Romano, G. Passiante, P.D. Vecchio, G. Secundo, The innovation ecosystem as booster for the innovative entrepreneurship in the smart specialisation strategy, Int. J. Knowl. Base. Dev. 5 (3) (2017) 271–288.
[35] D. Sjodin, Knowledge processing and ecosystem co-creation for process innovation: managing joint knowledge processing in process innovation projects, Int. Enterpren. Manag. J. 15 (1) (2019) 135–162.
[36] K. Tang, J. Ouyang, H. Ren, J. Cheng, What kind of innovation ecosystem can produce high innovation performance in high-tech zones: a fuzzy set qualitative comparative analysis based on 116 cases, Sci. Sci. Manag. S.& T 43 (7) (2022) 116–134.
[37] A. Albahari, A. Barge-Gil, S. Perez-Canto, A. Modrego, The influence of science and technology park characteristics on firms' innovation results, Pap. Reg. Sci. 97 (2) (2018) 1–27.
[38] K.H. Chen, J.C. Guan, Measuring the efficiency of China's regional innovation systems: application of network data envelopment analysis (DEA), Reg. Stud. 46 (3) (2012) 355–377.
[39] Z.Y. Liu, X.F. Chen, J.F. Chu, Q.Y. Zhu, Industrial development environment and innovation efficiency of high-tech industry: analysis based on the framework of innovation systems, Technol. Anal. Strateg. Manage. 30 (4) (2018) 434–446.
[40] E.J. Altman, M.L. Tushman, Platforms, open/user innovation, and ecosystems: a strategic leadership perspective, Adv. Strat. Manag. 37 (1) (2017) 177–207.
[41] K.Y.A. Chan, L.A.G. Oerlemans, M.W. Pretorius, Knowledge exchange behaviours of science park firms: the innovation hub case, Technol. Anal. Strateg. Manage. 22 (2) (2010) 207–228.
[42] T. Ratinho, E. Henriques, The role of science parks and business incubators in converging countries: evidence from Portugal, Technovation 30 (4) (2010) 278–290.
[43] B. Han, Q. Li, M. Zhu, C. Zhang, An evaluation of the inequality development of high-tech development zones in China based on the theory of entropy, Stud. Sci. Sci. (3) (2005) 342–346.
[44] I. Diez-Vial, M. Fernandez-Olmos, The effect of science and technology parks on firms' performance: how can firms benefit most under economic downturns? Technol. Anal. Strateg. Manage. 29 (10) (2017) 1153–1166.
[45] O. Dedehayir, S.J. Makinen, J.R. Ortt, Roles during innovation ecosystem genesis: a literature review, Technol. Forecast. Soc. Change 136 (2018) 18–29.
[46] K. Hewett, G.T.M. Hult, M.K. Mantrala, N. Nim, K. Pedada, Cross-border marketing ecosystem orchestration: a conceptualization of its determinants and boundary conditions, Int. J. Res. Market. 39 (2) (2022) 619–638.
[47] Á.R. Vásquez-Urriago, A. Barge-Gil, A.M. Rico, Science and technology parks and cooperation for innovation: empirical evidence from Spain, Res. Pol. 45 (1) (2016) 137–147.
[48] H. Jiao, J.H. Zhou, T.S. Gao, X.L. Liu, The more interactions the better? The moderating effect of the interaction between local producers and users of knowledge on the relationship between r&d investment and regional innovation systems, Technol. Forecast. Soc. Change 110 (2016) 13–20.
[49] N. Corrocher, F. Lamperti, R. Mavilia, Do science parks sustain or trigger innovation? Empirical evidence from Italy, Technol. Forecast. Soc. Change 147 (2019) 140–151.
[50] G. Jucevicius, K. Grumadaite, Smart development of innovation ecosystem, Procedia-Social and Behavioral Sciences 156 (2014) 125–129.
[51] J. Choi, A. Sang-Hyun, M.S. Cha, The effects of network characteristics on performance of innovation clusters, Expert Syst. Appl. 40 (11) (2013) 4511–4518.
[52] J. Shi, Y. Su, Behavioural strategies of manufacturing firms for high-quality development from the perspective of government participation: a three-part evolutionary game analysis, Heliyon 9 (4) (2023) e14982.
[53] H.A. Simon, A behavioral model of rational choice, Q. J. Econ. 69 (1) (1955) 99–118.
[54] J.M. Smith, G.R. Price, The logic of animal conflict, Nature 246 (1973) 15–18.
[55] J. Guadix, J. Carrillo-Castrillo, L. Onieva, J. Navascués, Success variables in science and technology parks, J. Bus. Res. 69 (11) (2016) 4870–4875.