mathematics

MDPI

Article

Technological Innovation Investment Channels of Industry–University–Research Alliance Enterprises and Non-Alliance Enterprises Based on Evolutionary Game

Qixuan Tang *, Chengjun Wang and Tao Feng

School of Management, Xi'an University of Architecture and Technology, Xi'an 710055, China; cjwang@xauat.edu.cn (C.W.); xauatft@xauat.edu.cn (T.F.)
* Correspondence: tqx0039@xauat.edu.cn

Abstract: According to their resource ownership and resource acquisition channels, this paper constructs an evolutionary game model of enterprises' technological innovation investment channels considering managers' expectations. This results in the strategy of non-alliance firms along the first channel having a significant impact on the evolutionary equilibrium. For non-alliance enterprises, the difference in the amount of investment in the R&D stage has the same impact on the probability of such enterprises following the first channel. The number of active managers, group capacity, the difference in managers' expectations, and the difference in the amount of technological innovation investment in the R&D stage have significant differences in the possibility of choosing the first channel between the two types of enterprises. The research conclusions can provide valuable references for enterprises to make technological innovation decisions.

Keywords: evolutionary game; industry–university–research alliance; technological innovation; investment channels

MSC: 35Q91

check for updates

Citation: Tang, Q.; Wang, C.; Feng, T. Technological Innovation Investment Channels of Industry–University–Research Alliance Enterprises and Non-Alliance Enterprises Based on Evolutionary Game. *Mathematics* **2024**, *12*, 289. https://doi.org/10.3390/math12020289

Academic Editor: Chuangyin Dang

Received: 28 November 2023
Revised: 28 December 2023
Accepted: 14 January 2024
Published: 16 January 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The theory of technological innovation points out that enterprise managers often take the enterprise's profit maximization as the basic reference point when making innovation investment decisions. In the actual analysis process, researchers often simplify the subjective attitude of managers in decision-making [1]. However, the existing research believes that the decision-making result is the process of managers' re-integration of existing knowledge, decision-making experience, and innovation willingness, which will eventually be transferred to the decision-making result [2]. To this end, scholars use the options game method to analyze the technological innovation investment decision. Although this method has some breakthroughs in the rationality of decision-makers, it has the disadvantage of simplifying the real option value at each stage of technological innovation [3]. In fact, the decision-making process of enterprises for technological innovation projects can be regarded as the real option execution process of enterprises in R&D, production, marketization, and other stages. In different stages of technological innovation investment, the amount of resources owned by enterprises, the access channels, the scope of resource links, and the degree of government support are obviously different [4], which leads to the difference in managers' judgment on the future opportunity value of the project, which then leads to the question of the analysis method of the traditional option game method. In addition, Li and Gao proposed a two-stage real option value evaluation method for the opportunity value analysis of investment projects, which ignores the value interaction between multiple composite options [5]. In order to overcome this shortcoming, some

scholars analyzed the investment process and investment characteristics of enterprise technology innovation and believed that the existing real option evaluation method had the shortcoming of simplification, and all enterprise managers believed that there was only one way to invest in the process of enterprise technology innovation, that is, to invest along the way of continuous expansion of investment amount [6]. This shows that traditional research believes that managers will expect the same future opportunity value of comfortable technological innovation investment projects. An important reason for this phenomenon is that researchers ignore the resource characteristics of enterprises themselves. For example, in an industry–university–research alliance, compared with non-alliance enterprises, alliance enterprises have obvious advantages in terms of innovation resource ownership, access to innovation resources, and resource link degrees [7]. Under this advantage, the alliance enterprises and the non-alliance enterprises cannot have the same investment amount in each stage of technological innovation investment. In this context, the expectation of enterprise managers on the future opportunity value of technological innovation and the characteristics of technological innovation investment of industry–university–research alliance enterprises and non-alliance enterprises are incorporated into the same analytical framework to explore the investment channel and strategy selection of the two types of enterprises in technological innovation. It has important practical significance and theoretical value for the government, alliance enterprises, and non-alliance enterprises to make technological innovation decisions.

In terms of research methods, the current research mainly focuses on the future opportunity value evaluation of technological innovation investment projects and the game method considering the option value. In terms of the future opportunity value evaluation of technological innovation investment projects, scholars mainly analyze the benefits and feasibility of technological innovation investment by optimizing the real option value evaluation model [8,9]. The representative ones include Roberto et al., who proposed a model based on real options to evaluate the uncertainty in the process of technological innovation because decision tree analysis and internal rate of return did not properly consider the problem of uncertainty and flexibility [10]. The study found that the factors affecting the future opportunity value of the project are the probability distribution of the project value and the production profit. Based on the analysis of CEO turnover of S&P 1500 companies, Jillian et al. found that in the literature on technological innovation, the duality theory highlights that innovation often comes from leaders who can make decisions under ambiguous circumstances and the R&D intensity and acquisition intention of a single firm, and the R&D intensity of the industry and the total investment increase the innovation ability of a firm [11]. Based on the real option valuation model, Cécile et al. analyzed the impact of patent-secured loans on the intellectual property rights and innovation strategies of technology enterprises that benefited from patent-secured loans and found that innovation investment and innovation strategy updating the speed of enterprises are closely related to the future opportunity value of projects when considering patent-secured loans [12]. Although the above research points out that the value of innovation projects has an important impact on the innovation input of enterprises in the process of technological innovation, the specific evaluation of project value does not point out the basis. Therefore, Mircea et al. constructed a prediction model of enterprise technology innovation behavior considering real option portfolio investment with growth options as the starting point [13]. The model abstracts the uncertainty into geometric Brownian motion and points out that technological factors should have important reference value in the relationship with innovators and socioeconomic and financial factors. In terms of the game method considering the option value, the representative ones are You et al., who combined the Poisson process and the traditional duopoly option game model to analyze the breakthrough technology innovation behavior. At the same time, they re-designed the marketization index of the breakthrough technology innovation results and tested the effectiveness of the new model with a real case [3]. Katja and Arne used the game model to analyze the technological innovation decision of electric vehicle enterprises [14]. The study

found that electric vehicle enterprises will consider both high risk and competition in the process of technological innovation, and there are significant differences in the expectations of different enterprise managers for the future opportunity value of the project in the process of competition. Chang et al. used the real options theory to evaluate the value of enterprises' technological innovation investment projects, constructed a game model based on deferred options, and obtained the optimal strategy Nash equilibrium [15]. The study found that due to the high cost of enterprises' technological innovation investment and the crowded flow of information, investors cannot make an immediate decision every time.

In addition, some scholars compare the application of existing real option evaluation methods in the field of technological innovation and find that these methods have the following problems [16–19]:

(1) Traditional real option evaluation methods tend to simplify the R&D process when analyzing the technological innovation process, which leads to the opportunity value of technological innovation projects not being accurately estimated.

(2) The traditional option game method assumes that the manager is not subjective, and the value of the technological innovation project is a fixed value, which is not affected by the manager's expectation.

In order to promote the solution to the above problems, Alessandri et al. explored the interaction between managers' behaviors and agents' interests, as well as the impact of these interactions on R&D investment, but this study did not reasonably divide the technological innovation projects into stages [20]. This paper argues that the current literature does not deeply analyze the entire investment process of technological innovation (this paper distinguishes between R&D and technological innovation; R&D only includes the stage of product R&D, while technological innovation includes the stage of product R&D, production preparation, and production). If the enterprise does not carry out the patent transformation of its own investment after successful R&D, the utility obtained by the enterprise cannot be fully mined. In terms of the option game, the current research mainly assumes that the players in the game are completely rational, ignoring the fact that managers will constantly adjust their strategies and collect information during the actual investment process [21,22].

In terms of research objects, Anamika et al. [23] studied the relationship between investment in technological innovation and entrepreneurial approaches and argued that access to resources and the ability of communities to technologically transform these resources depend on the basis of institutional guarantees and the attitude of taking risks to transform ecological changes into investment opportunities for firms. Based on China's provincial data and panel data model from 2000 to 2015, Lin and Zhu explored the response of renewable energy technology innovation to carbon dioxide-intensive emissions and concluded that carbon dioxide emissions in China's provinces had a significant role in promoting renewable energy technology innovation [24]. Based on the data of Chinese photovoltaic enterprises from 2012 to 2016, Lin and Luan found that financial leverage and ownership concentration have a significant positive impact on the innovation efficiency of China's photovoltaic industry, while firm size has a significant negative impact on the innovation efficiency of China's photovoltaic industry [25]. Although the above research points out that the improvement of innovation capability lies in building innovation alliances and making decisions based on the characteristics of the industry to which the enterprise belongs, the policy differences with the region are ignored. In view of this, Anis and Tarek studied how good governance and technological innovation supplement foreign direct investment to reduce carbon emissions in 23 emerging economies from 1996 to 2014 based on the generalized method of moments [26]. The interaction between GTI input and FDI reduces carbon dioxide emissions. In addition, due to the diversity of enterprise technology innovation alliances, namely, the cooperation between enterprises and enterprises, the cooperation between enterprises and universities and research institutes, and the cooperation between enterprises and governments, it is necessary to provide differentiated decision-making methods for the selection of partners. Therefore, Jiang et al. used

cooperative game theory to analyze the benefit distribution mechanism of technological innovation cooperation among enterprises in view of the stability problem of technological innovation cooperation alliances composed of multiple enterprises and pointed out that when the synergy coefficient of cooperation between enterprises is positive, enterprises can improve the benefit of technological innovation through cooperative alliances [27]. Ma and Li used the fixed effect model to test the impact of environmental regulation on enterprise technological innovation and the moderating effect of government subsidies and further analyzed from the perspective of ownership heterogeneity [28]. However, this study does not incorporate firm heterogeneity into the analysis framework. In reality, firm heterogeneity and policy heterogeneity coexist. For example, the heterogeneity of enterprise technological innovation is the private information that the government cannot obtain, which leads to the failure of traditional innovation support to achieve its goal [29].

By summarizing and analyzing the existing relevant literature, it can be found that first, the current analysis of the decision value of the technological innovation process simplifies the future opportunity value of the investment, replaces the project opportunity value with a single real option, and does not consider the interaction between opportunity values; secondly, the current literature considers that enterprise managers are rational decision-makers, and there is no difference in the risk perception of managers for technological innovation investment during the decision-making process. In practice, the factors affecting technological innovation investment are complex and changeable, and the technological innovation investment of enterprises has the characteristics of multiple stages. At each stage, enterprise managers have the right to make additional investments, reduce investment, or even withdraw [30], which makes the technological innovation investment of enterprises obviously multi-stage. This further aggravates the complexity of the interaction between the real option value in each stage [31]. Therefore, the conclusion drawn by using a single real option value as a proxy variable for the future opportunity value of the project is not convincing. In addition, the existing theory points out that it is impossible for enterprise managers to make completely rational decisions, and the decision-making results are affected by managers' subjective attitudes, such as risk preference, career experience, knowledge level, innovation enthusiasm, and innovation willingness [32].

Based on this, this paper first analyzes the investment stage of enterprise technological innovation and then clarifies the real option value and its interaction between each stage. Secondly, based on the results of a multi-stage analysis of enterprise technological innovation, the evolutionary game model of the industry–university–research alliance enterprises and non-alliance enterprises is constructed. Thirdly, the sensitivity of the game system equilibrium to the main parameters is analyzed by an example to show the influence of the main parameters on the choice of technological innovation paths of the industry–university–research alliance enterprises and non-alliance enterprises. Finally, this paper is summarized and puts forward some suggestions. For the convenience of narration, this paper regards the enterprises and their managers in the game as a whole; that is, the number of enterprises is equal to the number of managers, and the enterprises are uniformly regarded as managers when making behavioral decisions.

2. Model Construction

2.1. Technological Innovation Investment Channels and Different Managers' Expectations

The existing research shows that the investment in technological innovation has the characteristics of a long time span and phased investment, and the investment in technological innovation runs through the whole process of product R&D and formal production. Different investment strategies are the comprehensive reflection of managers' judgment on the future opportunity value and risk of the project [33]. In order to reasonably analyze the input strategies of enterprises participating in the industry–university–research alliance and non-alliance enterprises, this paper divides the technological innovation input of the two types of enterprises into three input stages: R&D (stage 1), production

preparation (stage 2), and formal production (stage 3) based on the theory of technological innovation input. Figure 1 presents the interaction of real options at each stage.

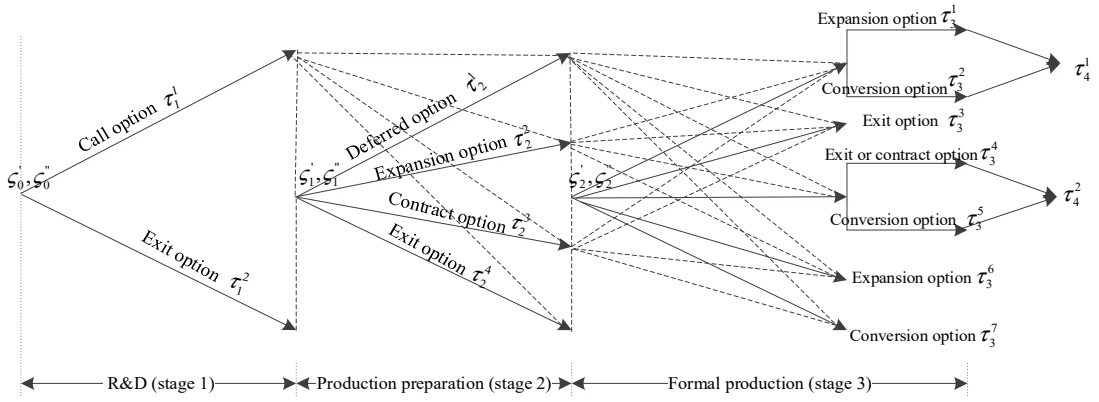


Figure 1. The three-stage composite option interaction mechanism in the process of technological innovation investment. Note: ς_0', ς_0'', ς_1', ς_1'', ς_2' and ς_2'' respectively represent the present value of the input amount of the industry–university–research alliance enterprises and non-alliance enterprises in each stage.

It can be seen from Figure 1 that in the process of technological innovation investment, the investment decisions of enterprises are more and more selective with the continuous advancement of innovation. At the starting point of each investment stage, enterprise managers can evaluate the value of future opportunities in this stage according to the amount of information they have and the degree of risk preference, which further constitutes the enterprise's investment strategy. If the real option value is transferred to the formal production stage, although four paths are formed at the input endpoint, the input channels can be divided into two according to the interaction of the real option. This is because real options τ_4^1 include real options τ_3^6 and τ_3^7, real options τ_4^2 include real options τ_3^7, and the final types of real options can be exercised selectively. In view of this, this paper defines the way for technological innovation input to reach τ_4^1 as the first channel (called the real option value τ_4^1, which is the upper limit of the opportunity value of the enterprise's technological innovation input), and the way for technological innovation input to reach τ_4^2 as the second channel (called the real option value τ_4^2, which is the lower limit of the opportunity value of the enterprise's technological innovation input). Based on this, it can be assumed that the managers of enterprises participating in the game all believe that the investment will continue to the end of the formal production stage (otherwise, they will not participate in the technological innovation competition), and different enterprises have different expectations on the opportunity value of the last stage of technological innovation investment. Therefore, the two groups of enterprise managers can be divided into active managers and passive managers. Active managers believe that the opportunity value of enterprise technological innovation will eventually reach the end of the formal production stage along the first channel, while passive managers believe that the opportunity value of enterprise technological innovation will eventually reach the end of the formal production stage along the second channel.

2.2. Model Hypothesis

Based on the fact that enterprises participating in industry–university–research alliances (referred to as alliance enterprises) have obvious advantages in resource acquisition and access channels compared with those not participating in industry–university–research alliances (referred to as non-alliance enterprises), this paper assumes that enterprises participating in technological innovation investment can be divided into two types: alliance enterprises and non-alliance enterprises. One enterprise is randomly selected from each group to play the game of technological innovation investment, and both types of enter-

prises have two kinds of strategic choices of investment along the first channel and the second channel. The managers and their enterprises are treated equally; that is, the number of managers is equal to the number of enterprises, and the strategy choice behavior of enterprise managers represents the strategy choice behavior of enterprises. Based on this, the following hypotheses are put forward:

(1) Compared with non-alliance enterprises, alliance enterprises have obvious advantages in the process of technological innovation, such as wide access to resources, fast information acquisition, easy access to state finance, R&D subsidies, and project investment, so the amount of capital owned by alliance enterprises is more than that of non-alliance enterprises. That is, in terms of the amount of technological innovation investment in the three stages, $\varsigma_0' > \varsigma_0''$, $\varsigma_1' > \varsigma_1''$, $\varsigma_2' > \varsigma_2''$ is established. where ς_0', ς_1', ς_2' respectively represents the technological innovation investment amount of the alliance enterprises in the above three stages, and ς_0'', ς_1'', ς_2'' respectively represents the technological innovation investment amount of the non-alliance enterprises in the above three stages.

(2) The investment of the two types of enterprises in the R&D stage is mainly the salary of technological innovation personnel, and the investment in the production preparation stage and the formal production stage is mainly in the purchase of fixed assets. Therefore, compared with non-alliance enterprises, the loss caused by the failure of investment in the first channel ($\varsigma_0' - \varsigma_0''$) is more than that caused by the failure of investment in the second channel of non-alliance enterprises.

(3) Since the purpose of the two enterprises participating in the competition is to obtain more market benefits, if the two enterprises play the game of technological innovation, the profits of both enterprises participating in the game will decrease. When everyone in authority adopts the strategy of investing in technological innovation along the first channel, then R is used to represent the average amount of profit reduction of the alliance enterprises and the non-alliance enterprises. When both alliance enterprises and non-alliance enterprises invest in technological innovation along the second channel, L can be used to represent the amount by which the profits of both types of enterprises are reduced.

Based on the above hypothesis, if $\frac{k}{K}$ is the proportion of the number of active managers in the initial stage of technological innovation investment to the total number of enterprise managers involved in technological innovation investment, then the proportion of the number of passive managers in the total number of enterprise managers involved in technological innovation investment is $1 - \frac{k}{K}$, where k represents the number of active managers, and K represents the total number of enterprise managers involved in technological innovation investment (also known as group capacity). Based on the above assumptions and variable definitions, the payoff matrices of alliance enterprises m_1 and non-alliance enterprises m_2 in the competitive environment are shown in Table 1 below.

Table 1. Technological innovation input payment matrix of alliance enterprises and non-alliance enterprises.

Investment of Alliance Enterprises m_1	**Investment of Non-Alliance Enterprises m_2**	
	First Channel (x_2^1,y)	**Second Channel (x_2^2,$1-y$)**
First channel (x_1^1, x)	$(\tau_4^1 - 2\varsigma_0' - \varsigma_1' - \varsigma_2' + \varsigma_0'' - R, \tau_4^1 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'' - R)$	$(\tau_4^1 - 2\varsigma_0' - \varsigma_1' - \varsigma_2' + \varsigma_0'', \tau_4^2 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'')$
Second channel ($x_1^2, 1-x$)	$(\tau_4^2 - \varsigma_0' - \varsigma_1' - \varsigma_2', \tau_4^1 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'')$	$(\tau_4^2 - \varsigma_0' - \varsigma_1' - \varsigma_2' - L, \tau_4^2 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'' - L)$

In Table 1, x represents the proportion of the number of enterprises adopting the first channel investment strategy to the total number of all the alliance enterprises, x_1^1, x_1^2 represent the technological innovation investment strategies of the alliance enterprises along the first and second channels, respectively; y represents the proportion of the number of non-alliance enterprises that invest along the first channel to the total number of all non-alliance enterprises; and x_2^1, x_2^2 represent the technological innovation investment strategies of non-alliance enterprises along the first and second channels, respectively.

2.3. Equilibrium Analysis of Stable Strategies in Evolutionary Games

The evolutionary game theory of corporate decision-making holds that in the game system, the strategies of the players are not static but change constantly over time, and the interaction between the strategies of all players can reach the equilibrium state at a certain stage. This is because, in the process of decision-making, the environment faced by managers and their own information, resources, and cognitive levels are changing, based on which enterprise managers will constantly adjust their strategies, and then make the opportunity value judgment of enterprise managers in the stage of technological innovation investment jump phenomenon. If the expected value of the future opportunity value of the technological innovation project of all the enterprise managers participating in the game is A, then the expected value is

$$A = [E(\frac{k}{K})\tau_4^1 + (1 - E(\frac{k}{K}))\tau_4^2] \tag{1}$$

where the stochastic process $\frac{k}{K}$ is a jump Markov chain. Based on this, if the transition rate expected by managers from choosing the second channel to the first channel is denoted by r, and the transition rate from choosing the first channel to the second channel is denoted by q, then according to the transition principle of physical electron potential energy, the transition rate when the electron potential energy changes can be obtained to obtain the expected change degree of enterprise managers, that is, the transition rate is

$$r = (1 - \frac{k}{K})\frac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})} + e^{\gamma h(\frac{k}{K})}}, q = (\frac{k}{K})\frac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})} + e^{\gamma h(\frac{k}{K})}}$$

Here, γ represents the uncertainty formed by the internal and external environment of the enterprise. The smaller γ is, the greater the uncertainty is, and vice versa; $h(\frac{k}{K})$ represents the mean of the difference in utility available to managers of alliance enterprises and non-alliance enterprises.

In order to solve $E(\frac{x}{K})$ in Equation (1), referring to the research of Wang and Sun [34], the utility function is in a linear form, namely $h(x) = -x + 0.5$. In addition, the evolutionary game theory points out that the dynamics of the evolutionary process are mainly reflected in the fitness transformation of the payoff function because there is a one-to-one correspondence between the fitness function and the game strategy [35]. Based on this, this paper assumes that the individual fitness function of the alliance enterprises when it invests along the first channel is

$$\begin{aligned} f_1(x_1^1) = {} & y(1 - \tfrac{k}{K})(\tfrac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})} + e^{\gamma h(\frac{k}{K})}})(\tau_4^1 - 2\varsigma_0' - \varsigma_1' - \varsigma_2' + \varsigma_0'' - R) \\ & + (1 - y)(\tfrac{k}{K})(\tfrac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})} + e^{\gamma h(\frac{k}{K})}})(\tau_4^1 - 2\varsigma_0' - \varsigma_1' - \varsigma_2' + \varsigma_0'') \end{aligned} \tag{2}$$

The fitness function of the individual when investing along the second channel is

$$\begin{aligned} f_2(x_1^2) = {} & y(1 - \tfrac{k}{K})(\tfrac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})} + e^{\gamma h(\frac{k}{K})}})(\tau_4^2 - \varsigma_0' - \varsigma_1' - \varsigma_2') \\ & + (1 - y)(\tfrac{k}{K})(\tfrac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})} + e^{\gamma h(\frac{k}{K})}})(\tau_4^2 - \varsigma_0' - \varsigma_1' - \varsigma_2' - L) \end{aligned} \tag{3}$$

At this time, the overall average fitness function of enterprises in the industry–university–research alliance is:

$$E(s_1) = xf_1(x_1^1) + (1 - x)f_2(x_1^2) \tag{4}$$

Therefore, the adjustment speed of the alliance enterprises to their technological innovation investment strategy (called group replicator dynamics) is

$$\begin{aligned}\frac{dx}{dt} = x(f_1(x_1^1) - E(s_1)) = x(1-x)(f_1(x_1^1) - f_2(x_1^2)) = x(1-x)(y(1-\tfrac{k}{K})(\tfrac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}}) \\ (\tau_4^1 - \tau_4^2 + \varsigma_0'' - \varsigma_0' - R) + (1-y)(\tfrac{k}{K})(\tfrac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})(\tau_4^1 - \tau_4^2 + \varsigma_0'' - \varsigma_0' + L))\end{aligned} \tag{5}$$

Similarly, the individual fitness function of desirable non-alliance enterprises when they invest along the first channel is

$$\begin{aligned}f_3(x_2^1) = x(1-\tfrac{k}{K})(\tfrac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})(\tau_4^1 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'' - R) \\ +(1-x)(\tfrac{k}{K})(\tfrac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})(\tau_4^1 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'')\end{aligned}$$

When non-alliance enterprises choose to invest in innovation along the second channel, the individual fitness function is

$$\begin{aligned}f_4(x_2^2) = x(1-\tfrac{k}{K})(\tfrac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})(\tau_4^2 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'') + (1-x)(\tfrac{k}{K})(\tfrac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}}) \\ (\tau_4^2 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'' - L)\end{aligned}$$

From this, the overall average fitness function of non-alliance enterprises can be obtained.

$$E(s_2) = yf_3(x_2^1) + (1-y)f_4(x_2^2)$$

Therefore, the adjustment speed of non-alliance enterprises to their innovation investment strategy is determined.

$$\begin{aligned}\frac{dy}{dt} = y(f_3(x_2^1) - E(s_2)) = y(1-y)(f_3(x_2^1) - f_4(x_2^2)) \\ = y(1-y)[x(1-\tfrac{k}{K})(\tfrac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})(\tau_4^1 - \tau_4^2 - R) \\ +(1-x)(\tfrac{k}{K})(\tfrac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})(\tau_4^1 - \tau_4^2 + L))\end{aligned} \tag{6}$$

To simplify the analysis, note

$$\psi_1 = \tau_4^1 - \tau_4^2 + \varsigma_0'' - R - \varsigma_0',\ \psi_2 = \tau_4^1 - \tau_4^2 + \varsigma_0'' - \varsigma_0' + L,\ \psi_3 = \tau_4^1 - \tau_4^2 - R,\ \psi_4 = \tau_4^1 - \tau_4^2 + L$$

It is easy to conclude: $\psi_4 > 0$, $\psi_4 > \psi_3 > \psi_1$, $\psi_4 > \psi_2 > \psi_1$
Combined with Table 1, we can obtain

$$(\tau_4^1 - 2\varsigma_0' - \varsigma_1' - \varsigma_2' + \varsigma_0'' - R) - (\tau_4^2 - \varsigma_0' - \varsigma_1' - \varsigma_2') = \tau_4^1 - \tau_4^2 + \varsigma_0'' - \varsigma_0' - R = \psi_1$$

That is, ψ_1 represents the relative net income of the alliance enterprises when the non-alliance enterprises invests along the first channel (the relative net income here refers to the difference between the income that can be obtained by investing along the first channel and the income that can be obtained by investing along the second channel).

$$(\tau_4^1 - 2\varsigma_0' - \varsigma_1' - \varsigma_2' + \varsigma_0'') - (\tau_4^2 - \varsigma_0' - \varsigma_1' - \varsigma_2' - L) = \tau_4^1 - \tau_4^2 + \varsigma_0'' - \varsigma_0' + L = \psi_2$$

That is, ψ_2 represents the relative net benefit value of the alliance enterprises when the non-alliance enterprises chooses the second channel of investment.

$$(\tau_4^1 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'' - R) - (\tau_4^2 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'') = \tau_4^1 - \tau_4^2 - R = \psi_3$$

That is, ψ_3 represents the relative net income of the non-alliance enterprises when the alliance enterprises invests along the first channel.

$$(\tau_4^1 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'') - (\tau_4^2 - \varsigma_0'' - \varsigma_1'' - \varsigma_2'' - L) = \tau_4^1 - \tau_4^2 + L = \psi_4$$

That is, ψ_4 represents the relative net profit value of non-alliance enterprises when the alliance enterprises choose the second channel of investment.

Let Equations (5) and (6) represent zero, respectively (the system of differential equations formed by these two equations represents the replication dynamic system of strategy selection of both parties), and the equilibrium points of the game system can be solved as (0,0), (0,1), (1,0), (1,1), (x^*, y^*), where

$$x^* = \frac{(\frac{k}{K})\psi_4}{(\frac{k}{K})\psi_4 - e^{2\gamma h(\frac{k}{K})}(1-\frac{k}{K})\psi_3},\ y^* = \frac{(\frac{k}{K})\psi_2}{(\frac{k}{K})\psi_2 - e^{2\gamma h(\frac{k}{K})}(1-\frac{k}{K})\psi_1}$$

The Jacobian matrix of the replicator dynamic equation is

$$J = \begin{pmatrix} (1-2x)[y(1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_1 & x(1-x)[(1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_1 \\ +(1-y)(\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_2] & -(\frac{n}{N})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_2] \\ y(1-y)[(1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_3 & (1-2y)[x(1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_3 \\ -(\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_4] & +(1-x)(\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_4] \end{pmatrix}$$

Furthermore, the determinant and trace of matrix J are obtained as

$$\det J = (1-2x)(1-2y)\{xy(1-\tfrac{k}{K})^2(\tfrac{e^{\gamma h(\frac{k}{K})}}{e^{\gamma(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}})^2)\psi_1\psi_3 + y(1-x)(\tfrac{k}{K})(1-\tfrac{k}{K})(1/(e^{\gamma h(\frac{k}{K})}+$$

$$e^{-\gamma h(\frac{k}{K})})^2)\psi_1\psi_4 + x(1-y)(\tfrac{k}{K})(1-\tfrac{k}{K})(1/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2)\psi_2\psi_3] + (1-x)(1-y)(\tfrac{k}{K})^2(e^{-2\gamma h(\frac{k}{K})}$$

$$/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2)\psi_2\psi_4\} - x^2y^2(1-x)(1-y)\{(1-\tfrac{k}{K})^2(e^{2\gamma h(\frac{k}{K})}/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2)\psi_1\psi_3 -$$

$$(\tfrac{k}{K})(1-\tfrac{k}{K})(1/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2)\psi_1\psi_4 - (\tfrac{k}{K})(1-\tfrac{k}{K})(1/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2)\psi_2\psi_3 + (\tfrac{k}{K})^2$$

$$(e^{-2\gamma h(\frac{k}{K})}/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2)\psi_2\psi_4\}$$

$$\mathrm{tr}J = (1-2x)(y(1-\tfrac{k}{K})(e^{\gamma h(\frac{k}{K})}/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}))\psi_1 + (1-y)(\tfrac{k}{K})(e^{-\gamma h(\frac{k}{K})}/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}))\psi_2)$$

$$+(1-2y)(x(1-\tfrac{k}{K})(e^{\gamma h(\frac{k}{K})}/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}))\psi_3 + (1-x)(\tfrac{k}{K})(e^{-\gamma h(\frac{k}{K})}/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}))\psi_4)$$

By substituting the equilibrium points (0,0), (0,1), (1,0), (1,1), and (x^*, y^*) into the above two equations, the matrix determinants and traces corresponding to the equilibrium points of the game can be obtained as shown in Table 2.

It can be seen from the above analysis that the replicator dynamics have nonlinear characteristics in the game process, and the solution of the game is not unique in this case, but the purpose of the game mechanism can be clarified through the equilibrium analysis. According to the knowledge of game theory, the stable point of the evolutionary game system satisfies the condition $\det J > 0$, $\mathrm{tr}J < 0$, and the strategy corresponding to the stable point is the stable strategy. Based on this, the stability of the equilibrium points of the evolutionary game of technological innovation input of the alliance and non-alliance enterprises under five different scenarios is shown in Tables 3 and 4.

Table 2. Expressions of matrix determinants and traces corresponding to equilibrium points in evolutionary games.

Equilibrium Point	Determinant and Trace
(0,0)	$\det J = (\frac{k}{K})^2(\frac{e^{-2\gamma h(\frac{k}{K})}}{(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2})\psi_2\psi_4$
	$\mathrm{tr}J = (\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}})(\psi_2+\psi_4)$
(1,0)	$\det J = -(\frac{k}{K})(1-\frac{k}{K})(1/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2)\psi_2\psi_3$
	$\mathrm{tr}J = -(\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}})\psi_2 + (1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}})\psi_3$
(0,1)	$\det J = -(\frac{k}{K})(1-\frac{k}{K})(\frac{1}{(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2})\psi_1\psi_4$
	$\mathrm{tr}J = (1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}})\psi_1 - (\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}})\psi_4$
(1,1)	$\det J = (1-\frac{k}{K})^2(\frac{e^{\gamma h(\frac{k}{K})}}{(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})})^2})\psi_1\psi_3$
	$\mathrm{tr}J = -(1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}})(\psi_1+\psi_3)$
(x^*, y^*)	$\det J = \frac{(\frac{k}{K})^3(1-\frac{k}{K})e^{2\gamma h(\frac{k}{K})}(e^{-\gamma h(\frac{k}{K})}/(e^{\gamma h(\frac{k}{K})}+e^{-\gamma h(\frac{k}{K})}))^3\psi_2^2v_3\psi_4}{((\frac{k}{K})\psi_4-(1-\frac{k}{K})e^{2\gamma h(\frac{k}{K})}\psi_3)\cdot((\frac{k}{K})\psi_2-(1-v)e^{2\gamma h(\frac{k}{K})}\psi_1)}$
	$\mathrm{tr}J = -\frac{(\frac{k}{K})(e^{-\gamma h(\frac{k}{K})}/(e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})})\psi_2\cdot((\frac{k}{K})\psi_4+(1-\frac{k}{K})e^{2\gamma h(\frac{k}{K})}\psi_3)}{(\frac{k}{K})\psi_4-(1-\frac{k}{K})e^{2\gamma h(\frac{k}{K})}\psi_3}\frac{(1-\frac{k}{K})e^{2\gamma h(\frac{k}{K})}\psi_1+(\frac{k}{K})\psi_2}{(\frac{k}{K})\psi_2-(1-\frac{k}{K})e^{2\gamma h(\frac{k}{K})}\psi_1}$

Table 3. Local stability of equilibrium points of evolutionary game between alliance and non-alliance enterprises (scenarios 1, 2, and 3).

Equilibrium Point	Scenario 1: $\psi_1<0$, $\psi_2>0$, $\psi_3>0$			Scenario 2: $\psi_1<0$, $\psi_2<0$, $\psi_3<0$			Scenario 3: $\psi_1<0$, $\psi_2<0$, $\psi_3<0$		
	det$J$	tr$J$	Stability	det$J$	tr$J$	Stability	det$J$	tr$J$	Stability
(0,0)	+	+	Unstable	−	Uncertainty	Unstable	+	+	Unstable
(1,0)	−	Uncertainty	Unstable	−	Uncertainty	Unstable	−	Uncertainty	Unstable
(0,1)	+	−	ESS	+	−	ESS	−	Uncertainty	Unstable
(1,1)	−	Uncertainty	Unstable	+	+	Unstable	+	−	ESS
(x^*, y^*)	Non-existence	Non-existence	Non-existence	Non-existence	Non-existence	Non-existence	Non-existence	Non-existence	Non-existence

Note: Here "+" means positive sign, "−" means negative sign, "ESS" stands for evolutionary stable strategy."Uncertainty" refers to the transition rate when the specific positive and negative types of tr$J$ change from the expectations of the managers of the two types of enterprises, the number of active managers, the number of passive managers, the mean of the difference in utility available to the enterprises, the amount of technological innovation input of the two types of enterprises in the three stages of R&D, production preparation and formal production, the upper and lower limits of the value of future opportunities, and the changes in the benefits of both parties caused by competition and other joint decisions. "Non-existence" means that the solution of x^*, y^* conflicts with the constraints $0 \le x^* \le 1, 0 \le y^* \le 1$, and there is no corresponding value of det$J$ and tr$J$.

Table 4. Stability of equilibrium points of evolutionary game between alliance and non-alliance enterprises (Scenarios 4 and 5).

Equilibrium Point	Scenario 4: $\psi_1<0$, $\psi_2<0$, $\psi_3>0$			Scenario 5: $\psi_1<0$, $\psi_2>0$, $\psi_3<0$		
	det$J$	tr$J$	Stability	det$J$	tr$J$	Stability
(0,0)	−	Uncertainty	Unstable	+	+	Unstable
(1,0)	+	+	Unstable	+	−	ESS
(0,1)	+	−	ESS	+	−	ESS
(1,1)	−	Uncertainty	Unstable	+	+	Unstable
(x^*, y^*)	Non-existence	Non-existence	Non-existence	−	Uncertainty	Saddle point

Here "+" means positive sign, "−" means negative sign, "ESS" stands for evolutionary stable strategy.

Based on Tables 3 and 4, comparing the stability of the first four different scenarios, it can be seen that the relative net benefit of the alliance when the non-alliance enterprises choose the second channel input and the relative net benefit of the non-alliance enterprises

when the alliance enterprises choose the first channel input has no effect on the equilibrium of the evolutionary game. However, when the non-alliance enterprises choose the first channel input, the relative net benefits of the alliance firms are positive or negative; that is, whether the non-alliance enterprises invest in technological innovation along the first channel has an impact on the equilibrium of the evolutionary game. When non-alliance enterprises choose the first channel to invest in technological innovation, when the relative net return of the alliance enterprises is negative, more alliance enterprises will invest in technological innovation along the second channel until all the alliance enterprises follow the investment strategy of the second channel to reach a steady state. When the relative net return of the non-alliance enterprises is positive, more alliance enterprises will invest in technological innovation along the second channel until all the alliance enterprises do not follow the investment strategy of the second channel and reach a steady state. In addition, for the alliance enterprises in scenario 5, it can be set

$$\frac{dx}{dt} = F(x) = x(1-x)[y(1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_1 + (1-y)(\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_2] = 0$$

Thus, the steady state of the evolutionary game in this scenario is $x = 0,\ x = 1$. If the initial state level in this scenario satisfies $y < y^*$, then $F(x) > 0$, $F'(0) > 0$, $F'(1) < 0$ can be obtained. Combined with the stability theory of partial differential equations, only $x = 1$ is a stable state in this scenario. If the initial state level in this scenario satisfies $y > y^*$, then $F(x) > 0$, $F'(0) < 0$, $F'(1) > 0$. can be obtained, and $x = 0$ is a stable state.

For non-alliance enterprises, we can let

$$\frac{dy}{dt} = F(y) = y(1-y)[x(1-\frac{k}{K})(\frac{e^{\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_3 + (1-x)(\frac{k}{K})(\frac{e^{-\gamma h(\frac{k}{K})}}{e^{-\gamma h(\frac{k}{K})}+e^{\gamma h(\frac{k}{K})}})\psi_4] = 0$$

Thus, $y = 0,\ y = 1$ is a stable state. If the initial state level in this scenario satisfies $x < x^*$, then $F(y) > 0$, $F'(0) > 0$, $F'(1) < 0$ can be obtained. In this case, $y = 1$ is a steady state. If the initial state level in this scenario satisfies $x > x^*$, then $F(y) > 0$, $F'(0) < 0$, $F'(1) > 0$ can be obtained. In this case, $y = 0$ is a steady state. Based on this, it can be seen that the saddle point $(x^*,\ y^*)$ of the game divides the evolutionary game phase diagram of technological innovation investment of the two types of enterprises into the following four regions, as shown in Figure 2.

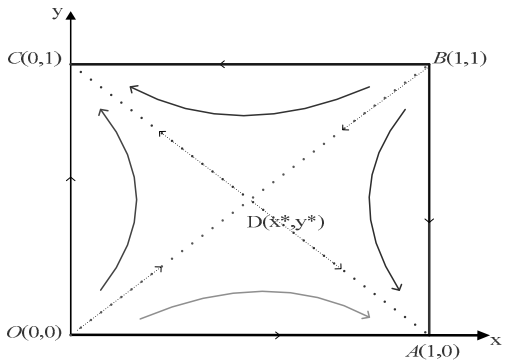


Figure 2. Phase diagram of game system evolution of alliance and non-alliance enterprises under scenario 5.

It can be seen from Figure 2 that when the initial state of the game system of the alliance and non-alliance enterprises is located in the regional *OABDO*, the game system of the two types of enterprises in this scenario gradually evolves and stabilizes at point *A*(1,0). The alliance enterprises invest in technological innovation along the first channel, and the non-alliance enterprises invest in technological innovation along the second channel. When the initial state of the game system is located in *OCBDO*, the game system of the two types

of enterprises will gradually evolve and stabilize at point $C(0,1)$. The alliance enterprises will invest in technological innovation along the second channel, and the non-alliance enterprises will invest in technological innovation along the first channel. The larger the area Φ_{OABDO} of regional $OABDO$, the more inclined the alliance enterprises are to invest in technological innovation along the first channel. The larger the area Φ_{OCBDO} of regional $OCBDO$, the more inclined the alliance enterprises are to invest in technological innovation along the second channel.

Combined with the results of the evolutionary game stability analysis of technological innovation input of alliance enterprises and non-alliance enterprises under the above scenarios, the evolutionary game stability strategies under different scenarios can be found, as shown in Table 5 below. In scenario 3, when $\psi_1 > 0, \psi_2 > 0, \psi_3 > 0$ is established, both alliance enterprises and non-alliance enterprises tend to invest along the first channel. In scenario 5, when $\psi_2 > 0, \psi_3 > 0$ is established, the alliance enterprises tend to invest in the first channel, the non-alliance enterprises tend to invest in the second channel, and vice versa. For scenarios 1, 2, and 4, the alliance enterprises tend to invest along the second channel, while the non-alliance enterprises tend to invest along the first channel.

Table 5. Game evolution stable strategies of technological innovation investment of alliance and non-alliance enterprises under the five scenarios.

Scenarios	ψ_1	ψ_2	ψ_3	ψ_4	Evolutionarily Stable Strategy
1	−	+	+	+	(Second channel input, first channel input)
2	−	−	−	+	(Second channel input, first channel input)
3	+	+	+	+	(First channel input, first channel input)
4	−	−	+	+	(Second channel input, first channel input)
5	−	+	−	+	(First channel input, second channel input) (Second channel input, first channel input)

Here "+" means positive sign, "−" means negative sign.

It can be seen from Table 5 that the game evolution strategies of technological innovation investment of the two types of enterprises are the same or different under different scenarios. In general, no matter whether for alliance or non-alliance enterprises, only when all the relative net returns of the two types of enterprises are positive will the alliance and non-alliance enterprises invest in technological innovation along the same channel (all along the first channel, when the competition is intensified, the two types of enterprises will actively innovate). Otherwise, the two types of enterprises invest in different channels. We compare the five scenarios, and it can be seen that only under scenario 3 will the two types of enterprises choose the first channel, the market competition is the strongest, and the social welfare increases the fastest. In addition, it can also be seen from Table 5 that in most scenarios, when the game system reaches the equilibrium state, the non-alliance enterprises finally choose to invest along the first channel. This shows that wide resource acquisition channels, large resource ownership, and strong resource linking and sharing capabilities do not mean fast R&D speed and high investment in technological innovation. It also proves that non-alliance enterprises are more competitive in innovation enthusiasm and willingness than alliance enterprises.

2.4. Sensitivity of Evolutionary Equilibrium of Game System to Main Parameters in Scenario 5

According to the evolutionary game theory, the analysis of the influencing factors of regional area Φ_{OABDO} can be transformed into the analysis of the influencing factors of the evolutionary stable equilibrium of the game system composed of the two types of enterprises. Based on the above analysis, there are

$$\Phi_{OABDO} = \frac{1}{2}\left(\frac{\left(\frac{k}{K}\right)\psi_4}{\left(\frac{k}{K}\right)\psi_4 - e^{2\gamma h\left(\frac{k}{K}\right)}\left(1-\frac{k}{K}\right)\psi_3} + \frac{\left(\frac{k}{K}\right)\psi_2}{\left(\frac{k}{K}\right)\psi_2 - \left(1 - e^{2\gamma h\left(\frac{k}{K}\right)}\left(\frac{k}{K}\right)\right)\psi_1}\right) \tag{7}$$

It can be seen from this equation that there are four factors that have an impact on the area Φ_{OABDO} and are related to the subjective cognition of managers. On this basis, the following four theorems are obtained:

Theorem 1. *The more active managers there are, the more likely the alliance enterprises are to choose the first channel for technological innovation investment, and the less likely the non-alliance enterprises are to choose the first channel for technological innovation investment (see Appendix A for the specific certification process).*

Theorem 2. *When* $\gamma \in (0, 2)$ *is the proxy variable of internal and external uncertainty factors, the larger the group capacity is, the more likely the alliance enterprises will choose the first channel to invest in technological innovation, and the less likely the non-alliance enterprises will choose the first channel to invest in technological innovation.*

When the proxy variable $\gamma \in [2, +\infty)$ of internal and external uncertainty factors and the group capacity is located in the interval $(\gamma K - k\sqrt{\gamma(\gamma-2)},\ \gamma k + k\sqrt{\gamma(\gamma-2)})$, the larger the group capacity is, the more likely the alliance enterprises will choose the first channel to invest in technological innovation, and the less likely the non-alliance enterprises will choose the first channel to invest in technological innovation.

When the proxy variable $\gamma \in [2, +\infty)$ of internal and external uncertainty factors and the group capacity is located in the interval $(-\infty, \gamma k - k\sqrt{\gamma(\gamma-2)}) \cup (\gamma k + k\sqrt{\gamma(\gamma-2)}, +\infty)$, the larger the group capacity is, the smaller the possibility that the alliance enterprises chooses the first channel to invest in technological innovation, and the greater the possibility that the non-alliance enterprises choose the first channel to invest in technological innovation (see Appendix B for the specific certification process).

Theorem 3. *The greater the difference in managers' expectation on the future opportunity value of the project is, the more likely the alliance enterprises are to choose the first channel for technological innovation investment, and the less likely the non-alliance enterprises are to choose the first channel for technological innovation investment (see Appendix C for the specific certification process).*

Theorem 4. *The greater the difference in the amount of investment in the R&D stage is, the more likely the alliance enterprises are to choose the first channel for technological innovation investment, while the less likely the non-alliance enterprises are to choose the first channel for technological innovation investment (see Appendix D for the specific certification process).*

Based on the above four theorems, it can be seen that under scenario 5, the number of active managers, managers' expectation of future opportunity value of the project, and the difference in investment amount in the R&D stage have important effects on the investment channel of the alliance and non-alliance enterprises. The sensitivity of the game equilibrium to the above factors is in the same direction, that is, with the increase of the corresponding parameters, the more likely the alliance enterprises are to invest in technological innovation along the first channel, and the less likely the non-alliance enterprises are to invest in technological innovation along the first channel. For the group capacity participating in the game, its influence on the regional area Φ_{OABDO} is also constrained by the value interval of the proxy variable of internal and external uncertainty factors.

3. Analysis of Numerical Examples

Since scenarios 1, 2, 3, and 4 all have only one evolutionary stable point, scenario 5 has two evolutionary stable points (parameter sensitivity analysis has been performed in Section 2.4). Therefore, this paper does not carry out parameter sensitivity simulation for scenario 5, and now carries out sensitivity simulation analysis of four parameters for scenarios with only one evolutionary stable point: (1) the number of active managers k; (2) group capacity K; (3) differences in managers' expectations $\tau_4^1 - \tau_4^2$; (4) the difference of investment amount in the initial stage $\varsigma_0'' - \varsigma_0'$.

3.1. Influence of the Number of Active Managers on the Evolution Results of the Game System

Based on the previous research on the relationship between the future opportunity value of the project and the amount of investment in each investment stage [36,37], and based on the previous experiments, we obtained the actual value range of the relevant parameters. In order to analyze the dynamic relationship between different parameters, we take specific values of related parameters. Therefore, the simulation in this paper is carried out under this premise, assuming that the parameter assignments of the model species are $\tau_4^1 = 4.5$, $\tau_4^2 = 1.5$, $\varsigma_0' = 8$, $\varsigma_0'' = 5$, $R = 2$, $L = 1$ (unit: CNY ten thousand), $\gamma = 2$, $K = 100$, the initial value of investment strategy is $x_0 = 0.5$, $y_0 = 0.5$, and the influence of different numbers of active managers on the evolution results of the game system is shown in Table 6 below.

Table 6. Effects of different numbers of active managers on the evolutionary outcomes of the game system.

	Alliance Enterprises (Probability of Choosing the First Channel)						**Non-Alliance Enterprises (Probability of Choosing the First Channel)**				
Time	***k* = 30**	***k* = 40**	***k* = 50**	***k* = 60**	***k* = 70**	**Time**	***k* = 60**	***k* = 70**	***k* = 80**	***k* = 90**	***k* = 100**
5	0.06	0.53	0.47	0.48	0.52	1	0.81	0.88	0.53	0.52	0.51
10	0.00	0.58	0.11	0.41	0.54	2	1.00	0.97	0.75	0.71	0.70
15	0.00	0.08	0.03	0.22	0.55	3	1.00	0.99	0.90	0.88	0.85
20	0.00	0.00	0.00	0.10	0.46	4	1.00	1.00	0.96	0.95	0.92
25	0.00	0.00	0.00	0.08	0.17	5	1.00	1.00	1.00	0.99	0.97
30	0.00	0.00	0.00	0.03	0.12	6	1.00	1.00	1.00	1.00	0.99
35	0.00	0.00	0.00	0.02	0.07	7	1.00	1.00	1.00	1.00	1.00
40	0.00	0.00	0.00	0.01	0.03	8	1.00	1.00	1.00	1.00	1.00
45	0.00	0.00	0.00	0.00	0.01	9	1.00	1.00	1.00	1.00	1.00
50	0.00	0.00	0.00	0.00	0.00	10	1.00	1.00	1.00	1.00	1.00

It can be seen from Table 6 that for the alliance enterprises, when the group capacity k is less than 50, with the increase of the group, the convergence time of the probability of the alliance enterprises choosing the first channel for technological innovation investment to the equilibrium state increases first and then decreases. When the group capacity k is greater than 50 and less than 100, the convergence time of the probability of selecting the first channel to the equilibrium state is increasing. For non-alliance enterprises, when the group capacity is less than 100, with the increase in sample size k, the convergence time of the probability of non-alliance enterprises choosing the first channel to the equilibrium state is decreasing. Comparing the alliance enterprises with the non-alliance enterprises, it can be seen that when the number of active managers is the same, the convergence speed of the probability of non-alliance enterprises choosing the first channel to the equilibrium state is faster than that of alliance enterprises.

3.2. Influence of Group Capacity on the Evolution Result of Game System

Similarly, if we take $\tau_4^1 = 4.5$, $\tau_4^2 = 1.5$, $\varsigma_0' = 8$, $\varsigma_0'' = 5$, $R = 2$, $L = 1$ (unit: CNY ten thousand), $\gamma = 2$, $k = 50$, the initial value of investment strategy is $x_0 = 0.5$, $y_0 = 0.5$, and the influence of different group capacity on the evolution results of the game system is shown in Table 7 below.

Table 7. The influence of different group capacity on the evolution results of the game system.

	Alliance Enterprises (Probability of Choosing the First Channel)						Non-Alliance Enterprises (Probability of Choosing the First Channel)				
Time	K **= 60**	K **= 70**	K **= 80**	K **= 90**	K **= 100**	**Time**	K **= 60**	K **= 70**	K **= 80**	K **= 90**	K **= 100**
5	0.35	0.49	0.06	0.26	0.56	1	0.68	0.65	0.56	0.54	0.52
10	0.16	0.00	0.00	0.07	0.62	2	1.00	0.98	0.79	0.68	0.63
15	0.09	0.00	0.00	0.00	0.58	3	1.00	1.00	0.92	0.86	0.80
20	0.04	0.00	0.00	0.00	0.41	4	1.00	1.00	0.99	0.94	0.87
25	0.01	0.00	0.00	0.00	0.14	5	1.00	1.00	1.00	0.99	0.97
30	0.00	0.00	0.00	0.00	0.10	6	1.00	1.00	1.00	1.00	1.00
35	0.00	0.00	0.00	0.00	0.06	7	1.00	1.00	1.00	1.00	1.00
40	0.00	0.00	0.00	0.00	0.03	8	1.00	1.00	1.00	1.00	1.00
45	0.00	0.00	0.00	0.00	0.01	9	1.00	1.00	1.00	1.00	1.00
50	0.00	0.00	0.00	0.00	0.00	10	1.00	1.00	1.00	1.00	1.00

It can be seen from Table 7 that for the alliance enterprises, when the group capacity K continues to increase, the convergence time of the probability of the alliance enterprises choosing the first channel for technological innovation investment to the equilibrium state decreases first and then increases. For the non-alliance enterprises, when the group capacity K keeps increasing, the convergence time of the probability of selecting the first channel to the equilibrium state keeps increasing. Comparing the alliance enterprises with the non-alliance enterprises, it can be seen that when the group capacity is the same, the probability of the non-alliance enterprises choosing the first channel to invest in technological innovation converges to the equilibrium state of the game system faster than the alliance enterprises.

3.3. Influence of the Difference in Expectation of Future Opportunity Value between the Two Types of Enterprise Managers on the Evolution Results of the Game System

Similar to Theorem 3, if we set $\theta = \tau_4^1 - \tau_4^2$ and take $\varsigma_0' = 8$, $\varsigma_0'' = 5$, $R = 2$, $L = 1$ (unit: CNY ten thousand), $\gamma = 2$, $k = 50$, $K = 100$, the amount of investment in the R&D stage is $x_0 = 0.5$, $y_0 = 0.5$, and the influence of the expected difference of future opportunity value between the two types of managers on the evolution results of the game system is shown in Table 8 below.

Table 8. The influence of the expected difference of future opportunity value between the two types of managers on the evolution results of the game system.

	Alliance Enterprises (Probability of Choosing the First Channel)						Non-Alliance Enterprises (Probability of Choosing the First Channel)				
Time	θ **= 2**	θ **= 3**	θ **= 4**	θ **= 5**	θ **= 6**	**Time**	θ **= 2**	θ **= 3**	θ **= 4**	θ **= 5**	θ **= 6**
2	0.44	0.47	0.56	0.52	0.58	1	0.51	0.54	0.61	0.63	0.65
3	0.17	0.41	0.58	0.47	0.05	2	0.52	0.62	0.65	0.93	1.00
4	0.06	0.35	0.51	0.08	0.00	3	0.61	0.83	1.00	1.00	1.00
5	0.02	0.18	0.42	0.04	0.00	4	0.86	0.94	0.97	1.00	1.00
6	0.00	0.13	0.22	0.00	0.00	5	0.90	0.97	1.00	1.00	1.00
7	0.00	0.10	0.18	0.00	0.00	6	0.92	1.00	1.00	1.00	1.00
8	0.00	0.08	0.08	0.00	0.00	7	0.96	1.00	1.00	1.00	1.00
9	0.00	0.06	0.06	0.00	0.00	8	0.99	1.00	1.00	1.00	1.00
10	0.00	0.03	0.04	0.00	0.00	9	1.00	1.00	1.00	1.00	1.00
11	0.00	0.02	0.03	0.00	0.00	10	1.00	1.00	1.00	1.00	1.00

It can be seen from Table 8 that for the alliance enterprises, when the expected difference of future opportunity value of enterprise managers θ keeps increasing, the convergence time of the probability of the alliance enterprises choosing the first channel to invest in technological innovation to the equilibrium state first increases and then decreases. For

non-alliance enterprises, when the expected difference of future opportunity value of enterprise managers θ keeps increasing, the time for the probability of selecting the first channel to converge to the equilibrium state keeps decreasing. Comparing the alliance enterprises with the non-alliance enterprises, it can be seen that when the expected difference of the future opportunity value of the managers is the same, the convergence time of the probability of the non-alliance enterprises choosing the first channel for technological innovation investment is basically the same as that of the alliance enterprises.

3.4. Influence of the Difference of Technological Innovation Investment in R&D Stage on the Evolution Result of Game System

Similar to Theorem 4, let $\xi = \varsigma_0'' - \varsigma_0'$ and take $\tau_4^1 = 4.5,\ \tau_4^2 = 1.5,\ R = 2,\ L = 1$ (unit: CNY ten thousand), $\gamma = 2$, $k = 50$, $K = 100$, the amount of investment in the R&D stage is $x_0 = 0.5,\ y_0 = 0.5$, and the influence of the difference in the amount of technological innovation investment in the R&D stage on the evolution results of the game system is shown in Table 9 below.

Table 9. The influence of the difference in the amount of technological innovation investment in the R&D stage on the evolution results of the game system.

	Alliance Enterprises (Probability of Choosing the First Channel)						**Non-Alliance Enterprises (Probability of Choosing the First Channel)**				
Time	$\xi = 2$	$\xi = 3$	$\xi = 4$	$\xi = 5$	$\xi = 6$	**Time**	$\xi = -2$	$\xi = -3$	$\xi = -4$	$\xi = -5$	$\xi = -6$
2	0.52	0.48	0.46	0.44	0.41	1	0.55	0.55	0.55	0.55	0.55
3	0.51	0.42	0.07	0.03	0.00	2	0.73	0.73	0.73	0.73	0.73
4	0.48	0.31	0.03	0.00	0.00	3	0.61	0.61	0.61	0.61	0.61
5	0.42	0.20	0.01	0.00	0.00	4	0.97	0.97	0.97	0.97	0.97
6	0.28	0.17	0.00	0.00	0.00	5	1.00	1.00	1.00	1.00	1.00
7	0.20	0.14	0.00	0.00	0.00	6	1.00	1.00	1.00	1.00	1.00
8	0.14	0.10	0.00	0.00	0.00	7	1.00	1.00	1.00	1.00	1.00
9	0.10	0.06	0.00	0.00	0.00	8	1.00	1.00	1.00	1.00	1.00
10	0.07	0.04	0.00	0.00	0.00	9	1.00	1.00	1.00	1.00	1.00
11	0.05	0.03	0.00	0.00	0.00	10	1.00	1.00	1.00	1.00	1.00

It can be seen from Table 9 that for the alliance enterprises, when the difference in technological innovation investment in the R&D stage ξ keeps increasing, the time for the probability of the alliance enterprises to choose the first channel to invest in technological innovation to converge to the equilibrium state gradually increases. For non-alliance enterprises, when the difference in technological innovation investment in the R&D stage ξ keeps increasing, the difference in investment amount in the R&D stage has no effect on the convergence of the probability of non-alliance enterprises choosing the first channel to the equilibrium state. By comparing the alliance enterprises with the non-alliance enterprises, it can be seen that when the difference in the two enterprises' technological innovation investment in the R&D stage is the same, the convergence speed of the probability of the non-alliance enterprises choosing the first channel to the equilibrium state is basically the same as that of the alliance enterprises.

Through the analysis of the above numerical examples, it can be seen that the number of active managers, group capacity, the expected difference of future opportunity value between the two types of enterprise managers, and the difference in technological innovation investment amount in the R&D stage have different effects on the probability of the two types of enterprises to choose the first channel of technological innovation investment. A firm's choice of the two approaches depends on its own and rival managers' expectations and the amount of technological innovation investment in the R&D stage. For non-alliance enterprises, the difference in technological innovation investment in the R&D stage has the same impact on the possibility of choosing the first channel. This shows that the willingness of non-alliance enterprises to succeed in technological innovation is more prominent than that of alliance enterprises. Whether it is an alliance enterprise or a non-alliance

enterprise, the managers' expectation of the future opportunity value of the project is the result of their judgment on the future market income of the enterprise and the future opportunity value of the project. The information resource channel, information quantity, and resource link degree obtained by the enterprise affect the amount of technological innovation investment in the R&D stage of the enterprise and the managers' willingness to innovate. Therefore, managers' expectations of the future opportunity value of projects and enterprises' resource acquisition channels and quantity are important influencing factors for the choice of technological innovation investment channels of alliance enterprises and non-alliance enterprises.

4. Conclusions and Management Suggestions

On the basis of clarifying the opportunity value of projects and their interaction in the stages of R&D, production preparation, and formal production in the process of technological innovation, this paper constructs an evolutionary game model of technological innovation investment decision-making of non-alliance enterprises and alliance enterprises and analyzes the equilibrium of the game and its constraints under five scenarios. The results show that:

(1) When the non-alliance enterprises invest in technological innovation along the second channel, the positive and negative values of the relative net benefits of the alliance enterprises, and when the alliance enterprises invest in technological innovation along the first channel, they have no effect on the equilibrium of the game system, but the strategy of the non-alliance enterprises investing in technological innovation along the first channel has an effect on the equilibrium of the game system. Therefore, in order to encourage enterprises to choose the first channel to invest in technological innovation, in the stage of R&D investment, non-alliance enterprises should combine their own resource advantages with the external environment to strengthen innovation cooperation, and the government should issue relevant policies on technology monopoly to promote the willingness of technological innovation of alliance enterprises and non-alliance enterprises and improve the stock of social welfare.

(2) When the non-alliance enterprises invest in technological innovation along the first channel and the relative net income of the alliance enterprises is negative, more alliance enterprises will invest in technological innovation along the second channel. Therefore, for the alliance enterprises, the government should issue relevant policies to optimize the organizational structure of the enterprises participating in the industry–university–research alliance. For example, for enterprises with failed management decisions and redundant resources, the government should issue relevant policies and regulations to optimize the structure of resources, stock, and cash flow invested in technological innovation.

(3) After analyzing the five scenarios, it is found that when the four scenarios appear, and the game system reaches the equilibrium state, non-alliance enterprises will invest in technological innovation along the first channel, which may be related to the degree of resource focus and innovation willingness of non-alliance enterprises. This conclusion further validates that technological innovation channels and acquisition of innovation resources are not the only indicators to promote enterprise technological innovation, and non-alliance enterprises have stronger survival pressure and innovation willingness than alliance enterprises in most scenarios.

(4) For non-alliance enterprises, the difference in R&D investment has the same impact on the possibility of their technological innovation investment along the first channel. This conclusion shows that non-alliance enterprises have more advantages in innovation success rate and innovation willingness. For the alliance enterprises, the government should formulate relevant policies to supervise the industry–university–research alliance and actively improve the fairness of technological innovation competition between the alliance enterprises and non-alliance enterprises.

(5) For non-alliance enterprises and alliance enterprises, the main factors affecting the investment channels of technological innovation of these two types of enterprises include

managers' enthusiasm, managers' expectation of the future opportunity value of the project, and the difference in investment amount in the R&D stage. When the values of the above factors increase, the probability of the alliance enterprises investing in technological innovation along the first channel is higher, but the probability of the non-alliance enterprises investing in technological innovation along the first channel is lower. Therefore, when the government makes a technological innovation incentive policy, it should treat the future opportunity value expectation of the two types of managers differently.

In this paper, the decision game between the enterprise of industry–university–research alliance and the enterprise of non-alliance in technological innovation investment is studied. The limitations of this study are as follows: (1) This study does not consider the individual differences of corporate decision-makers, such as the investment risk appetite of decision-makers. (2) In the process of enterprise technological innovation investment, different enterprises are subject to significantly different financing constraints. Based on this, in the next step, we will incorporate decision-makers' investment risk preferences into the game analysis, and consider the degree of financing constraints on different enterprises.

Author Contributions: Methodology, Q.T.; Formal analysis, C.W.; Resources, T.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China grant number 7187020620.

Data Availability Statement: The authors confirm that the data supporting the findings of this study are available within the article.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Proof. Let $k = z$ and take the partial derivative with respect to z of the area Φ_{OABDO} of the region

$$\frac{\partial \Phi_{OABDO}}{\partial z} = \frac{1}{2}\left(\frac{\psi_3\psi_4}{[\psi_4 - e^{-2\gamma(\frac{z}{K})+1}(\frac{K}{z})-1)\psi_3]^2} + \frac{\psi_1\psi_2}{[\psi_2 - e^{-2\gamma(\frac{z}{K})+1}(\frac{K}{z})-1)\psi_1]^2}\right) \left(-\frac{K}{z^2} - \frac{2\gamma}{z} + \frac{2\gamma}{K}\right)e^{-2\gamma(\frac{z}{K})+1}$$

It can be seen that the regional area Φ_{OABDO} is an increasing function of z, and the more active managers the game system converges to the equilibrium point (0,1), the less the convergence probability to the equilibrium point (1,0). In this case, the more likely the alliance enterprises are to choose the first channel for technological innovation investment, the less likely the non-alliance enterprises are to choose the first channel for technological innovation investment. □

Appendix B

Proof. Let the group capacity $K = w$ and take the partial derivative with respect to w of the area Φ_{OABDO} of the region

$$\frac{\partial \Phi_{OABDO}}{\partial w} = \frac{1}{2}\left(\frac{\psi_3\psi_4}{[\psi_4 - e^{-2\gamma(\frac{k}{w})+1}(\frac{w}{k}) - 1)\psi_3]^2} + \frac{\psi_1\psi_2}{[\psi_2 - e^{-2\gamma(\frac{k}{w})+1}(\frac{w}{k}) - 1)\psi_1]^2}\right)\left(\frac{2\gamma k - 2\gamma w}{w^2} + \frac{1}{k}\right)e^{-2\gamma(\frac{k}{w})+1}$$

When the proxy variable for the internal and external uncertainty factors is $\gamma \in (0, 2)$, the partial derivative of the region area Φ_{OABDO} with respect to w is positive, that is, inequalities $\frac{\partial \Phi_{OABDO}}{\partial w} > 0$ hold. Therefore, the area Φ_{OABDO} is an increasing function of group capacity K. When the group capacity is larger, the probability that the game system converges to the equilibrium point (0,1) is less than the probability that the game system

converges to the equilibrium point (1,0). At this time, the possibility that the alliance enterprises choose the first channel for technological innovation investment is greater, and the possibility that the non-alliance enterprises choose the first channel for technological innovation investment is smaller. When $\gamma \in [2, +\infty)$ is the proxy variable of internal and external uncertainty factors, if $w \in (\gamma k - k\sqrt{\gamma(\gamma-2)}, \gamma k + k\sqrt{\gamma(\gamma-2)})$, then the partial derivative of regional area Φ_{OABDO} with respect to w is non-negative, that is, inequality $\frac{\partial \Phi_{OABDO}}{\partial w} \geq 0$ holds.

When $w \in (-\infty, \gamma k - k\sqrt{\gamma(\gamma-2)}) \cup (\gamma k + k\sqrt{\gamma(\gamma-2)}, +\infty)$, then $\frac{\partial \Phi_{OABDO}}{\partial w} < 0$. Therefore, when the proxy variable $\gamma \in [2, +\infty)$ of internal and external uncertainty factors and the group capacity is located in interval $(\gamma k - k\sqrt{\gamma(\gamma-2)}, \gamma k + k\sqrt{\gamma(\gamma-2)})$, the area Φ_{OABDO} is an increasing function of the group capacity. When the group capacity is larger, the probability of convergence to the equilibrium point (0,1) is less than that to the equilibrium point (1,0). At this time, the more likely the alliance enterprises are to choose the first channel for technological innovation investment, the less likely the non-alliance enterprises are to choose the first channel for technological innovation investment.

When the proxy variable $\gamma \in [2, +\infty)$ of internal and external uncertainty factors and the group capacity is located in the interval $(-\infty, \gamma k - k\sqrt{\gamma(\gamma-2)}) \cup (\gamma k + k\sqrt{\gamma(\gamma-2)}, +\infty)$, the area Φ_{OABDO} is a decreasing function of the group capacity w. When the group capacity w increases, the probability of convergence of the game system to the equilibrium point (0,1) is greater than that to the equilibrium point (1,0), and the more likely non-alliance enterprises are to choose the first channel for technological innovation investment. □

Appendix C

Proof. If the difference in managers' expectations of the future opportunity value of the project is $\theta = \tau_4^1 - \tau_4^2$, then

$$\Phi_{OABDO} = \frac{1}{2}\left(\frac{(\frac{k}{K})(\theta+L)}{(\frac{k}{K})(\theta+L) - e^{-2\gamma(\frac{k}{K})+1}(1-\frac{k}{K})(\theta-R)} + \frac{(\frac{k}{K})(\theta+I_0''-I_0'+L)}{(\frac{k}{K})(\theta+\varsigma_0''-\varsigma_0'+L) - e^{-2\gamma(\frac{n}{K})+1}(1-\frac{k}{K})(\theta+\varsigma_0''-R-\varsigma_0')}\right)$$

The partial derivative of the manager's expected difference θ for the future opportunity and love of the project is obtained for the area Φ_{OABDO}:

$$\frac{\partial \Phi_{OABDO}}{\partial \theta} = \frac{1}{2}e^{-2\gamma(\frac{k}{K})+1}(\frac{k}{K})(1-(\frac{k}{K}))(L+R)\left(\frac{1}{[(\frac{k}{K})(\theta+L)-(1-(\frac{k}{K}))e^{-2\gamma(\frac{k}{K})+1}(\theta-R)]^2} + \frac{1}{[(\frac{k}{K})(\theta+\varsigma_0''-\varsigma_0'+L)-e^{-2\gamma(\frac{k}{K})+1}(1-\frac{k}{K})(\theta+\varsigma_0''-\varsigma_0'-R)]^2}\right) > 0$$

Therefore, the regional area Φ_{OABDO} is the increasing function of the managers' expected difference θ of the future opportunity value of the project. When the expected difference is greater, the probability that the game system converges to the equilibrium point (0,1) is less than that of the equilibrium point (1,0), and the alliance enterprises are more likely to choose the first channel to invest in technological innovation. The more likely the alliance enterprises are to choose the first channel for technological innovation investment, the less likely the non-alliance enterprises are to choose the first channel. □

Appendix D

Proof. Let the difference in the amount of investment in the R&D stage be $\xi = \varsigma_0'' - \varsigma_0'$, then

$$\Phi_{OABDO} = \frac{1}{2}\left(\frac{\left(\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2+L\right)}{\left(\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2+L\right)-e^{-2\gamma\left(\frac{k}{K}\right)+1}\left(1-\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2-R\right)} + \frac{\left(\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2+\xi+L\right)}{\left(\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2+\xi+L\right)-e^{-2\gamma\left(\frac{k}{K}\right)+1}\left(1-\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2+\xi-R\right)}\right)$$

The partial derivative of area Φ_{OABDO} with respect to the difference ξ in the amount of investment in the R&D stage is obtained:

$$\frac{\partial \Phi_{OABDO}}{\partial \xi} = \frac{1}{2}\left(\frac{\left(\frac{k}{K}\right)e^{-2\gamma\left(\frac{k}{K}\right)+1}\left(1-\frac{k}{K}\right)(R+L)}{\left[\left(\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2+\xi+L\right)-e^{-2\gamma\left(\frac{k}{K}\right)+1}\left(1-\frac{k}{K}\right)\left(\tau_4^1-\tau_4^2+\xi-R\right)\right]^2}\right) > 0$$

This shows that the regional area Φ_{OABDO} is an increasing function of the difference ξ in the amount of investment in the R&D stage. If the difference in the amount of investment in the R&D stage is greater, the probability of convergence to the equilibrium point (0,1) is less than that to the equilibrium point (1,0), and the possibility of the alliance enterprises choosing the first channel to invest in technological innovation is greater. The more likely the alliance enterprises are to choose the first channel for technological innovation investment, the less likely the non-alliance enterprises are to choose the first channel for technological innovation investment. □

References

1. Rajenlall, S. Technological and non-technological innovation effects on firm performance. *J. High Technol. Manag. Res.* **2022**, *33*, 100–114. [CrossRef]
2. Evan, M.F.; Stephanie, P.G.; Daniel, F.; Brittney, C.E.; Stephanie, M.M.; Cara, D. Promising technological innovations in cognitive training to treat eating-related behavior. *Appetite* **2018**, *124*, 68–77. [CrossRef]
3. You, D.; Yang, X.H.; Desheng, D.; Chen, G.F. Option game with Poisson Jump Process in company radical technological innovation. *Technol. Forecast. Soc. Change* **2014**, *81*, 341–350. [CrossRef]
4. Zheng, X.X.; Li, D.F. A new biform game-based investment incentive mechanism for eco-efficient innovation in supply chain. *Int. J. Prod. Econ.* **2023**, *258*, 125–136. [CrossRef]
5. Li, M.Y.; Gao, X. Implementation of enterprises' green technology innovation under market-based environmental regulation: An evolutionary game approach. *J. Environ. Manag.* **2022**, *308*, 245–260. [CrossRef]
6. Wei, Y.G.; Zhu, R.Q.; Tan, L.Y. Emission trading scheme, technological innovation, and competitiveness: Evidence from China's thermal power enterprises. *J. Environ. Manag.* **2022**, *320*, 314–356. [CrossRef] [PubMed]
7. Zhang, Y.F.; Yuan, C.H.; Zhang, S.M. Influences of university-industry alliance portfolio depth and breadth on growth of new technology-based firms: Evidence from China. *Ind. Mark. Manag.* **2022**, *102*, 190–204. [CrossRef]
8. Kyungtaek, K.; Deokjoo, L.; Sungjoon, P. Evaluation of R&D investments in wind power in Korea using real option. *Renew. Sustain. Energy Rev.* **2014**, *40*, 335–347. [CrossRef]
9. Wang, J.; Wang, C.Y.; Wu, C.Y. A real options framework for R&D planning in technology-based firms. *J. Eng. Technol. Manag.* **2015**, *35*, 93–114. [CrossRef]
10. Roberto, D.H.; David, G.C.; Idalia, P.J. A real option-based model for the valuation of patent protected technological innovation projects. *World Pat. Inf.* **2018**, *53*, 24–38. [CrossRef]
11. Jillian, A.; Joetta, F.; Charla, G.B.; Richard, C.W. The benefits of hiring a STEM CEO: Decision making under innovation and real options. *Technol. Soc.* **2022**, *71*, 102–114. [CrossRef]
12. Cécile, A.; Jamal, A.; Selma, B.; Julien, P. Revisiting the consequences of loans secured by patents on technological firms' intellectual property and innovation strategies. *Res. Policy* **2023**, *52*, 234–245. [CrossRef]
13. Mircea, B.; Catalin, C.; Victor, V.; Corina, E.B. An Active Support Instrument for Innovation in Deep Uncertainty-The Strategic Management Ingredients in Robotics and Mechatronics. *Procedia Comput. Sci.* **2015**, *65*, 210–217. [CrossRef]
14. Katja, L.; Arne, V. Business Model Gaming: A Game-Based Methodology for E-Mobility Business Model Innovation. *Procedia CIRP* **2017**, *64*, 115–120. [CrossRef]
15. Chang, S.; Li, Y.; Gao, F. The impact of delaying an investment decision on R&D projects in real option game. *Chaos Solitons Fractals* **2016**, *87*, 182–189. [CrossRef]
16. Lai, V.V.; Huong, T.L. Strategic growth option, uncertainty, and R&D investment. *Int. Rev. Financ. Anal.* **2017**, *51*, 16–24. [CrossRef]

17. Gonzalo, M.B.; Constancio, Z.R.; José, M.; González, G. Impact of flexibility in public R&D funding: How real options could avoid the crowding-out effect. *Renew. Sustain. Energy Rev.* **2017**, *76*, 813–823. [CrossRef]
18. Marta, B.; Giovanni, V. A fuzzy approach for R&D compound option valuation. *Fuzzy Sets Syst.* **2017**, *310*, 108–121. [CrossRef]
19. Denis, B.; Edgard, G. Real options valuation of fusion energy R&D programme. *Energy Policy* **2011**, *39*, 116–130. [CrossRef]
20. Alessandri, T.M.; Pattit, J.M. Drivers of R&D investment: The interaction of behavioral theory and managerial incentives. *J. Bus. Res.* **2014**, *67*, 151–158. [CrossRef]
21. Martzoukos, S.H.; Zacharias, E. Real option games with R&D and learning spillovers. *Int. J. Oi Manag. Soience* **2013**, *4*, 236–249. [CrossRef]
22. Bensoussan, A.; Diltz, D.J.; Hoe, S.R. Real options games in complete and incomplete markets with several decision makers. *Soc. Ind. Appl. Math.* **2010**, *1*, 666–728. [CrossRef]
23. Anamika, D.; Anil, K.G.; Gurdeep, S. Innovation, investment and enterprise: Climate resilient entrepreneurial pathways for overcoming poverty. *Agric. Syst.* **2019**, *172*, 83–90. [CrossRef]
24. Lin, B.Q.; Zhu, J.P. Determinants of renewable energy technological innovation in China under CO_2 emissions constraint. *J. Environ. Manag.* **2019**, *247*, 662–671. [CrossRef] [PubMed]
25. Lin, B.Q.; Luan, R.R. Do government subsidies promote efficiency in technological innovation of China's photovoltaic enterprises? *J. Clean. Prod.* **2020**, *254*, 120–134. [CrossRef]
26. Anis, O.; Tarek, B.H. Foreign investment and air pollution: Do good governance and technological innovation matter? *Environ. Res.* **2020**, *185*, 109–120. [CrossRef]
27. Jiang, X.H.; Wang, L.F.; Cao, B.; Fan, X.Y. Benefit distribution and stability analysis of enterprises' technological innovation cooperation alliance. *Comput. Ind. Eng.* **2021**, *161*, 234–246. [CrossRef]
28. Ma, H.D.; Li, L.X. Could environmental regulation promote the technological innovation of China's emerging marine enterprises? Based on the moderating effect of government grants. *Environ. Res.* **2021**, *202*, 1230–1241. [CrossRef]
29. Pan, J.D.; Lin, G.B.; Xiao, W. The heterogeneity of innovation, government R&D support and enterprise innovation performance. *Res. Int. Bus. Financ.* **2022**, *62*, 101–113. [CrossRef]
30. Liu, H.; Fan, L.B.; Shao, Z.X. Threshold effects of energy consumption, technological innovation, and supply chain management on enterprise performance in China's manufacturing industry. *J. Environ. Manag.* **2021**, *300*, 1560–1573. [CrossRef] [PubMed]
31. Wei, J.Y.; Wang, C.X. Improving interaction mechanism of carbon reduction technology innovation between supply chain enterprises and government by means of differential game. *J. Clean. Prod.* **2021**, *296*, 134–146. [CrossRef]
32. Chi, M.L.; Yue, K.K. Patent-investment games under asymmetric information. *Eur. J. Oper. Res.* **2012**, *223*, 441–451. [CrossRef]
33. Azzurra, M.; Serena, R.; Giovanna, L.N.; Paolo, R. A real options game of alliance timing decisions in biopharmaceutical research and development. *Eur. J. Oper. Res.* **2017**, *261*, 1189–1202. [CrossRef]
34. Wang, C.F.; Sun, J.C. Monetary Policy, Credit Constraints on Enterprises and Corporate R&D Investment Decision. *Manag. Rev.* **2017**, *29*, 17–27. Available online: https://journal05.magtech.org.cn/jweb_glpl/EN/Y2017/V29/I11/17 (accessed on 12 February 2019).
35. Xu, Q.; Belmonte, A.; de Forest, R.; Liu, C.; Tan, Z. Strong solutions and instability for the fitness gradient system in evolutionary games between two populations. *J. Differ. Equ.* **2017**, *262*, 4021–4051. [CrossRef]
36. Zhao, Z.W.; Lu, C.X. A Multi-stage Compound Real Option Model for Valvetion of Venture Capital Project. *J. Syst. Manag.* **2011**, *20*, 104–108. Available online: https://kns.cnki.net/kcms2/article/abstract?v=tc18asgQl7Qf5FQzOUivqkn4fcW-5bgoHSlnFp0uo6cwIIh3HUi4iqkc7cAINp2Fadhhkj99AOl8nc2NZVjI9ciH7Hv0w3Z3GJki-s3YFVL3XkrbcgH7VccWghyFTkt-&uniplatform=NZKPT&language=CHS (accessed on 23 March 2020).
37. Rolando, P.; Fernando, O.; Francisco, G. Real option valuation of power transmission investments by stochastic simulation. *Energy Econ.* **2015**, *47*, 215–226. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.