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Technology sharing game from ecological perspective

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Abstract

New technological revolution has brought about significant changes in technological innovation activities. The platform has become an indispensable part of the innovation ecosystem of technology-intensive enterprises, which is derived from enterprise technology sharing. The main relationship of the innovation ecosystem is competition and cooperation. We use evolutionary game theory to consider the sharing behaviour of two enterprises in terms of different implicit parameters, thereby providing insight into the design of innovation ecosystem and technology innovation platform policies that promote open and shared technological innovation.

Keywords: innovation ecosystem, technology innovation platform, technology sharing, evolutionary game.

AMS 2010 codes: 97M50; 91A22.

1 Introduction

With the rapid development and wide popularisation of new technologies such as artificial intelligence, big data and internet, the links between innovation subjects have become closer. Open innovation is increasingly becoming the mainstream paradigm. In this environment, the boundary of participants in the process of innovation input, output and commercialisation is increasingly blurred [1]. At present, innovation has entered the Innovation 3.0 paradigm with the innovation ecosystem as the core [2–4]. In the process of building an innovation ecosystem, organisational resources, scientific and technological resources, network resources and system resources interact and coevolve [5]. The process is not determined by a single mechanism but by all the sub-mechanisms and their interactions and linkages [6]. Among them, the relationship is complex; competition and cooperation blend mutually. The innovation ecosystem combines new ideas and technologies with products, services and production processes. It makes full use of technology, talents and other scientific and technological resources and makes use of technology innovation platform technology to conduct data mining and intelligent matching, which greatly improves the efficiency of resource utilisation and diffusion. In China, economic development entered the new normal, innovation-driven development has become the most fundamental driving force

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for development. At present, the economics of China aggregate ranks top in the world, but the technological level is generally not high. The contribution of science and technology to economic development is far lower than that of developed countries [7, 8].

2 Background and related work

To change the backward situation of science and technology, seize the development opportunities brought by the new round of scientific and technological revolution, China proposes the sharing economy model. This raises higher requirements for the development of enterprises. As an essential factor for enterprises to maintain competitive advantages, technological resources, especially heterogeneous technological resources, are of strategic significance to enterprises' innovation activities. More and more enterprises choose resource sharing strategy to seek additional benefits and market competitiveness. As a key element of innovation, technology has become what you want it to be. In the innovation ecosystem, the main innovation entities include enterprises, universities, scientific research institutions, and so on.

The supporting entities include government, financial and intermediary agencies. They gain technological advantages through competition and cooperation with each other.

In view of the importance of technology sharing, scholars have conducted a lot of research. From the perspective of patent, some scholars believe that technology sharing is difficult to be realised due to the monopoly of patent. This not only hinders the transfer and implementation of innovation achievements but also brings obstacles to the development of existing shared projects; therefore, it is necessary to build a patent open licence platform in combination with internet and other technologies so as to not only reserve patent rights for technology owners but also promote technology transfer and implementation [9]. In view of the research of technology sharing process, most scholars advocate the idea of evolutionary game. For example, Chen [10] studied the ecological niche evolution process of strategic emerging industries by using evolutionary game theory and found that cost, government subsidy, expected revenue and so on have an important influence on the niche evolution of strategic emerging industries. Zhao et al. [11] believed that resource sharing should be analysed as a decision-making process, which is embodied in the military–civilian integration and collaborative innovation. Other scholars believe that it is also reflected in cross-regional and cross-disciplinary innovation [12]. By means of evolutionary game theory, Wang [13] analysed the influencing factors of the evolution path of knowledge sharing among employees in innovative organisations and pointed out that appropriate incentives are conducive to knowledge sharing within organisations. Ho et al. [14] studied the direct correlation between knowledge sharing behaviour and strategy by using evolutionary game theory.

Some scholars assume different scenarios, such as Dan et al. [15] studied the competitive and cooperative game strategy of inventory technology sharing retailers' joint purchasing alliance by using inverse induction method under the stochastic demand situation, or from the perspective of weighing the relationship between patents and technology secrets, like Shen [16] studied patent synergies based on the evolutionary game model and proposed a way to share patents that could achieve better financial returns. Zhao [17] analysed and verified the impact of institutional constraints and inter-firm interaction learning on the protection strategy of evolutionary stability innovation under different situations through the evolutionary game and multi-agent modelling and simulation.

The current era is no longer the competition between enterprises but the competition between innovation ecosystems. If an enterprise only pursues temporary profit maximisation, it is likely to fail to keep up with its future development potential. In the end, it will be difficult to achieve sustainability and will inevitably end up in recession and bankruptcy. Based on the comprehensive analysis of the existing literature, it is found that the acquisition of technical resources is regarded as the benefit behaviour of enterprises, while the influence of the heterogeneity of enterprises is ignored. This is a potential impact, but it is also not negligible. Due to the difference of the enterprise itself, the technology absorption, adaptation, transformation and risk-bearing capacity of the enterprise are different. The accumulation of previous behaviours also leads to a different image

of the enterprise in the system. The conditions for different enterprises to choose technology sharing strategy will be different. The government needs to guide and support different situations, which is more conducive to the stable development of the innovation ecosystem; therefore, this article analyses the technology sharing strategies of enterprises in the innovation ecosystem of technology-intensive enterprises combined with multiple implicit influencing factors.

3 Assumptions and game model

3.1 The evolutionary game relationships

There is no core enterprise in the flat innovation ecosystem and no big strength gap between enterprises. Therefore, we extract two stakeholders: enterprise 1 and enterprise 2. They both play producer roles in the innovation ecosystem, mainly by virtue of technology to obtain product advantages and market competitiveness. The total amount of enterprise technology includes stock and trading. In the innovation ecosystem, technology sharing platforms are the most efficient and convenient way to trade. The enterprise can select from two strategies: sharing technology (we can call ‘sharing’) and not sharing technology, just get technology from the platform (‘non-sharing’). In the case of ‘sharing’, the enterprises will share their technologies to the platform in a certain proportion and search complementary or additional technologies that they need. In the situation of ‘non-sharing’, the enterprises only gain but do not contribute, which is referred to as ‘hitchhiking’.

The innovation ecosystem includes n corporate entities and four kinds of environments. All enterprises have equal status. Any two enterprises trade and share technology through technology innovation platform and will create a technology flow. As enterprise activities cross over on the platform, technology flows evolve from chains to networks. The government provides guarantee and direction for the systematic sustainable development policy environment through the regulation of system and the promulgation of major policies. Universities, scientific research institutions and other enterprises provide the starting point and foundation of technological innovation for the innovation ecosystem. Cultural environment comes from the whole society, mainly including the identity of entrepreneur and consumer, international relations. Technological innovation must be rooted in local culture and actively integrated with the international community. This has a profound impact on the development potential of enterprises. Market environment is the soil of enterprises’ growth. A good market environment will promote the development of whole technology innovation activities and promote the smooth operation of the ecosystem. The relationships of enterprises in the innovation ecosystem are shown in Figure 1.

Fig. 1 Innovation ecosystem relationships based on technology sharing.

3.2 Assumptions

- (1) In the flat technology-intensive innovation ecosystem, there are two players.
- (2) Game players are willing to share technology because for technology-intensive enterprises, technology stock is in direct proportion to their competitiveness. However, after acquiring new technologies, enterprises will ab-

Table 1 Game model parameters and connotations.

<i>Parameters</i>	<i>Connotations</i>
x_1	Probability that enterprise 1 chooses to share technology
x_2	Probability that enterprise 2 chooses to share technology
P	New technical value after sharing
P_1	Original technical value of enterprise 1
P_2	Original technological value of enterprise 2
r_1	Technical value distribution coefficient after sharing 1
r_2	Technical value distribution coefficient after sharing 2
N_1	The technical stock of enterprise 1
N_2	The technical stock of enterprise 2
α	Proportion of technology shared by enterprise 1
β	Proportion of technology shared by enterprise 2
τ_1	The time-delay coefficient of enterprise 1
τ_2	The time-delay coefficient of enterprise 2
K_1	Punishment for enterprise 1
K_2	Punishment for enterprise 2
μ	Constant
ε_1	The image factor of enterprise 1
ε_2	The image factor of enterprise 2
C_1	Technology sharing costs in enterprise 1, $C_1 = c_1 \alpha N_1$
C_2	Technology sharing costs in enterprise 2, $C_2 = c_2 \beta N_2$

Annotation: c_i is the shared cost coefficient, ε_i is the image factor of enterprise, the larger the value, the worse the image. α and β are the proportion of technology shared by enterprise, in this paper, we suppose that the proportion is determined before the enterprise decides whether to share the technology.

sorb and adapt them first and apply them to R&D and finally put new products into the market to obtain benefits. The whole process takes time to complete; we call this ‘time delay’. Considering the different absorptive capacity, adaptive capacity and application ability of the enterprise to technology, the time-delay coefficient will be different.

(3) Enterprise 1 has more advantages in technical resources, knowledge and information than enterprise 2, but not much.

(4) When both enterprises choose to share, they will attain more additional benefits than the situation where a single enterprise chooses to share.

(5) When one enterprise shares technology and another does not, the non-sharing enterprise will be punished by ecosystem maintainers such as the government. In view of the enterprise image, penalties will increase as ‘hitchhiking’ increases.

The parameters and connotations of the game model are shown in Table 1.

3.3 Game model

The payoff matrix among two players is established in Table 2. In Table 2, suppose that the willingness that enterprise 1 chooses the sharing strategy is x_1 , the willingness of choosing non-sharing is $1 - x_1$. Simultaneously, for enterprise 2, the willingness of sharing is x_2 , non-sharing is $1 - x_2$, where $0 \leq x_1 \leq 1$, $0 \leq x_2 \leq 1$.

Table 2 Payoff matrix.

		Enterprise 2	
		Sharing (x_2)	Non-sharing ($1 - x_2$)
Enterprise 1	Sharing (x_1)	$P_1N_1 + Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - C_1$ $P_2N_2 +$ $Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - C_2$	$P_1N_1 - C_1$ $P_2N_2 + P_1\alpha N_1e^{-\mu\tau_2} - \varepsilon_2K_2$
	Non-sharing ($1 - x_1$)	$P_1N_1 + P_2\beta N_2e^{-\mu\tau_1} - \varepsilon_1K_1$ $P_2N_2 - C_2$	P_1N_1 P_2N_2

4 Equilibrium analysis of evolutionary game

4.1 The analysis of equilibrium points

Supposing that E_{11} represents the expected earnings of enterprise 1 when adopt sharing strategy, E_{12} represents the expected earnings of enterprise 1 that chooses non-sharing strategy. $\bar{E}_1$ represents the expected earnings of enterprise 1 that choose the average return of both strategies. Then:

$$E_{11} = x_2 (P_1N_1 + Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - C_1) + (1 - x_2) (P_1N_1 - C_1) = x_2Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 + P_1N_1 - C_1$$

$$E_{12} = x_2 (P_1N_1 + P_2\beta N_2e^{-\mu\tau_1} - \varepsilon_1K_1) + (1 - x_2) P_1N_1 = x_2P_2\beta N_2e^{-\mu\tau_1} + P_1N_1 - x_2\varepsilon_1K_1$$

$$\bar{E}_1 = x_1E_{11} + (1 - x_1)E_{12} = x_1 (x_2Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 + P_1N_1 - C_1) + (1 - x_1) (x_2P_2\beta N_2e^{-\mu\tau_1} + P_1N_1 - x_2\varepsilon_1K_1)$$

The replicator dynamics equation of the willingness x_1 for enterprise 1 is

$$\frac{dx_1}{dt} = x_1 (E_{11} - \bar{E}_1) = x_1 (1 - x_1) [x_2 (Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1) - C_1]$$

In the same way, supposing that E_{21} represents the expected earnings of enterprise 2 when adopt sharing strategy, E_{22} represents the expected earnings of enterprise 2 that choose non-sharing strategy. $\bar{E}_2$ represents the expected earnings of enterprise 2 that choose the average return of both strategies. The replicator dynamic equation of the willingnessfor enterprise 1 is

$$\frac{dx_2}{dt} = x_2 (E_{21} - \bar{E}_2) = x_2 (1 - x_2) [x_1 (Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2) - C_2]$$

In the replicator dynamic system, make $\frac{dx_1}{dt} = 0$, $\frac{dx_2}{dt} = 0$. We can get 5 equilibrium points, which include

$$Q_1(0,0), Q_2(1,0), Q_3(0,1), Q_4(1,1)$$

$$Q_5\left(\frac{C_2}{Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2}, \frac{C_1}{Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1}\right).$$

4.2 Local stability analysis of equilibrium strategy

Since the local equilibrium point is not necessarily the evolution stability strategy (ESS) of system, the local stability analysis method of the Jacobi matrix is selected in this paper [18].

The Jacobi matrix of the evolutionary system is

$$J = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}.$$

Among them,

$$a_{11} = (1 - 2x_1)[x_2(Pe^{\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1) - C_1]$$

$$a_{12} = x_1(1 - x_1)(Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1)$$

$$a_{21} = x_2(1 - x_2)(Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2)$$

$$a_{22} = (1 - 2x_2)[x_1(Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2) - C_2]$$

Based on the Jacobi matrix, when an equilibrium point makes $Det(J) > 0, tr(J) < 0$, the point is a local asymptotic stability point, and the corresponding strategy is the system ESS. Five local equilibrium points were substituted into the matrix for calculation, and the results are shown in Table 3.

Table 3 Value of the Jacobi matrix at the local equilibrium

Stability point	a_{11}	a_{12}	a_{21}	a_{22}
Q_1	$-C_1$	0	0	$-C_2$
Q_2	C_1	0	0	$Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2 - C_2$
Q_3	$Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1 - C_1$	0	0	C_2
Q_4	$-Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 + P_2\beta N_2e^{-\mu\tau_1} - \varepsilon_1K_1 + C_1$	0	0	$-Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 + P_1\alpha N_1e^{-\mu\tau_2} - \varepsilon_2K_2 + C_2$
Q_5	0	M_1	M_2	0

Among Table 3,

$$M_1 = \frac{C_2(Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2 - C_2)(Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1)}{(Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2)^2}$$

$$M_2 = \frac{C_2(Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1 - C_1)(Pe^{-\mu\tau_2}r_2\alpha N_1\beta N_2 - P_1\alpha N_1e^{-\mu\tau_2} + \varepsilon_2K_2)}{(Pe^{-\mu\tau_1}r_1\alpha N_1\beta N_2 - P_2\beta N_2e^{-\mu\tau_1} + \varepsilon_1K_1)^2}$$

From Table 3, is the saddle point. It is not the stable strategy point because the trace of the determinant is 0. At the equilibrium points $Q_2(1, 0)$ and $Q_3(0, 1)$, the stability conditions of the Jacobi matrix are contradictory that cannot satisfy both conditions $Det(J) > 0$ and $tr(J) < 0$. So Q_2 and Q_3 are not stable strategy points. For the equilibrium points $Q_1(0, 0)$ and $Q_4(1, 1)$, according to different situations in the evolution process, namely, different values of various parameters, we will analyse the stability strategy under three conditions. The results of evolutionary stability analysis under different conditions are shown in Table 4.

ESS, evolution stability strategy.

(i) when $e^{-\mu\tau_1}\beta N_2(P_2 - Pr_1\alpha N_1) < C_1 - \varepsilon_1K_1, C_2 < \varepsilon_2K_2$ or $e^{-\mu\tau_2}\alpha N_1(P_1 - Pr_2\beta N_2) < C_2\varepsilon_2K_2, C_1 < \varepsilon_1K_1$ is the only stable point. At this time, the corresponding policy is that both enterprises choose non-sharing strategy. The phase evolution diagram is shown in Figure 2.

(ii) when $C_1 < \varepsilon_1K_1; C_2 < \varepsilon_2K_2, Q_1(0, 0)$ and $Q_4(1, 1)$ are both local stability points in the system. Representing two enterprises do not share technology and share technology strategy. Equilibrium points $Q_2(1, 0)$ and $Q_3(1, 1)$ are unstable points. Q_5 is the saddle point. The phase evolution diagram is shown in Figure 3. As shown in the triangle $\Delta Q_1Q_3Q_5$, when enterprise 1 chooses not to share technology, enterprise 2 will gradually lose its

Table 4 The evolutionary stability analysis under different conditions.

Equilibrium point	Condition 1	Condition 2	Condition 3
	$e^{-\mu\tau_1}\beta N_2(P_2 - Pr_1\alpha N_1)$; $\prec C_1 - \varepsilon_1 K_1$ $C_2 \prec \varepsilon_2 K_2$	$C_1 \prec \varepsilon_1 K_1$; $e^{-\mu\tau_2}\alpha N_1(P_1 - Pr_2\beta N_2)$ $\prec C_2 - \varepsilon_2 K_2$	$C_1 \prec \varepsilon_1 K_1$; $C_2 \prec \varepsilon_2 K_2$
Q_1	ESS	ESS	ESS
Q_2	Instability	Instability	Instability
Q_3	Instability	Instability	Instability
Q_4	Instability	Instability	ESS
Q_5	Saddle point	Saddle point	Saddle point

technological competitive advantage due to technology-following. In this way, enterprise 2 will be more and more inclined to choose the non-sharing strategy. $\Delta Q_1 Q_2 Q_5$ represents the initial situation that enterprise 1 chooses the strategy of sharing technology, but enterprise 2 does not. As time goes by and technology accumulates, when the shared technology of enterprise 1 acquired by enterprise 2 reaches a certain threshold, it will surpass enterprise 2 and become the enterprise with the most technical resources. At this point, enterprise will try to avoid this risk. Enterprise 1 will gradually change its strategy and eventually converge to the point (0,0). $\Delta Q_3 Q_4 Q_5$ indicates that with the increasing additional benefits brought by sharing technology from enterprise 2, enterprise 1 realises the importance of technology sharing. In order to maximise its own benefits, enterprise 1 also decides to implement the technology sharing strategy. And yet, the two enterprises enjoy mutualism and common development. The innovation ecosystem has also been further developed and transformed. The same, when enterprise 2 finds the importance of technology sharing from the sharing results of enterprise 2, it also recognises the technology sharing strategy and joins the symbiotic development team of the innovation ecosystem, which is shown in $\Delta Q_3 Q_4 Q_5$.

Fig. 2 Phase evolution diagram in scenario (i).

Fig. 3 Phase evolution diagram in scenario (ii)

5 Simulation example

To study the evolution process and rules of technology sharing strategy of enterprises in technology-intensive innovation ecosystem more clearly and deeply, we use a MATLAB simulation tool to simulate the evolution process [19–24]. The horizontal axis represents time (t), and the vertical axis represents enterprise's willingness to choose technology sharing strategy. 0 means non-sharing, 1 means sharing. To better express the situation that enterprises' sharing intention changes with the change of parameters, suppose that the initial willingness of all enterprises is 0.5, that is, all enterprises in the initial innovation ecosystem are in a neutral state.

According to the information of the actual production data of relevant enterprises, suppose that the technology stock of enterprise is $N_1 = 12$, $N_2 = 8$. The technology value is $P_1 = 10$, $P_2 = 8$. The technical value after the sharing strategy selected by both enterprises is $P = 15$. Income distribution coefficient of enterprise 1 is $r_1 = 0.6$, and enterprise 2's income distribution coefficient is $r_2 = 0.4$. The technology sharing behaviour of enterprise 1 will cost $C_1 = 10$, the sharing cost of enterprise (2) is $C_2 = 8$. When one enterprise chooses to share and another chooses not to share technology, the latter will be penalised $K_1 = 10$, $K_2 = 8$ and $\mu = 3$.

5.1 The influence of time-delay coefficient on enterprise sharing strategy

Enterprise has more technical advantages than enterprise 2, so suppose the technology transformation time of enterprise 1 is less than that of enterprise 2 and $\tau_1 = 0.4$, $\tau_2 = 0.5$. The proportion of technology sharing $\alpha = 0.5$ for enterprise (1), $\beta = 0.3$ for enterprise 2, and the image factor for enterprises ε is both 0.2.

When the time-delay coefficient of enterprise 2 is 0.5, and τ_1 takes different values, the sharing willingness of enterprise 1 changes over time, which is shown in the first picture of Figure 4. As the time-delay coefficient increases, enterprise 1 will be more inclined to non-sharing. The threshold is in the interval $[0.25, 0.3]$, when $\tau_1 < 0.25$, enterprise 1 will decisively choose to share technology. When $\tau_1 = 0.3$, enterprise 1 is in a state of hesitation. At first, there was a clear preference for sharing technology, but as time went on, enterprise 1 finally chooses not to share. When $\tau_1 > 0.3$, enterprise 1's hesitation time becomes shorter and shorter, and the willingness to share technology is becoming less obvious. In the end, it will choose not to share technology with other businesses in the innovation ecosystem. The second picture shows the change of technology sharing intention of enterprise 2 with time under different time-delay coefficients. The overall evolution law of enterprise 2 is similar to that of enterprise 1, and its threshold interval is $[0.35, 0.4]$.

When the time-delay coefficient of each enterprise is lower than its corresponding threshold, the enterprise will finally choose the sharing strategy. In the situation, the technology innovation platform will play its biggest role, and the innovation ecosystem will present a good situation of cooperation and symbiosis, promoting the further development of technology and economy; therefore, the ability of enterprise technology transformation plays an important role in technology transfer in the whole innovation ecosystem. All relevant parties should attach importance to improving the transformation level of technological achievements of enterprises, encourage

Fig. 4 The influence of τ on the shared strategy of enterprise.

enterprises to make good use of intelligent means, acquire complementary technologies and talents in various ways and strive to improve their ability to adapt to and absorb new technologies. At the same time, it is necessary to reduce the hesitation of enterprise decision-makers to avoid missing the opportunity of obtaining the best technology and marketing investment.

5.2 The influence of image factor on enterprise sharing strategy

The image factor represents the impression an enterprise leaves on the outside world. The smaller the image factor, the better the image of the enterprise in the whole ecosystem. This factor is related to the previous behaviour of the enterprise, for example, enterprises often break promises, default or 'hitchhiking' and so on, then the system is bound to be very difficult to tolerate their bad behaviour again. Enterprises have also been punished more severely. In the principle of encouraging in the system, if an enterprise with a clean bill of health accidentally 'hitchhiking', the system will treat it lightly. The enterprise will be less penalised. The image factor increases with the increase in the number of bad behaviours.

Supposing that $\alpha = 0.5$, $\beta = 0.3$, $\tau_1 = 0.45$, $\tau_2 = 0.5$, when $\varepsilon_2 = 0.5$, the willingness of enterprise 1 to choose technology sharing strategy increases with the increase in the image factor of enterprise 2 because the increase in the number of 'hitchhiking' means that the penalties for the enterprises are increased. Then enterprises will do their best to avoid excessive losses. Similarly, the trend of enterprises 2 is also direct proportionality curve. The threshold interval of both enterprise 1 and enterprise 2 is $[0.5, 0.55]$, which is shown in Figure 5. The influence of image factor on enterprises' choice of technology sharing strategy has nothing to do with the nature of enterprises, it is only about behaviour. When the image factor is higher than the threshold value, if the enterprise wants to continue to develop well in the ecosystem, its optimal strategy is sharing.

Fig. 5 The influence of ε on the shared strategy of enterprise.

Fig. 6 The influence of α and β on the shared strategy of enterprise.

5.3 The influence of proportion of technology on enterprise sharing strategy

When $\beta = 0.3$, $\alpha = 0.4$, as the proportion of one enterprise to choose technology sharing increases, the willingness of another to choose technology sharing becomes stronger. The technology sharing threshold interval of enterprise 1 is $[0.35, 0.4]$. It indicates that when enterprise 1 determines that 40% of the technology stock will be shared, the premise for its choice of sharing technology is that the technology sharing proportion of enterprise 2 is higher than the threshold $[0.35, 0.4]$. If the technology sharing ratio of enterprise 2 is lower than 0.35, enterprise 1 will finally choose non-sharing without too much hesitation. If the technology sharing ratio of enterprise 2 is higher than 0.4, enterprise 1 will not hesitate to choose technology sharing, and the sharing time will be shortened as the sharing ratio of the other party increases. When enterprise 2 decided to share 30% of its technology, then the threshold interval of enterprise 1 is $[0.55, 0.6]$. That is, when the threshold value is higher, enterprise 2 will choose the technology sharing strategy. Enterprise 2 has a period of hesitation when $\alpha = 0.55$, and as α decreases, the hesitation time decreases. When the technology sharing ratio of enterprise 1 is higher than 0.6, enterprise 2 will resolutely choose technology sharing to build a good technology sharing platform of innovation ecosystem together with enterprise 1. The change curve is shown in Figure 6.

By contrast, we find that when choosing strategy, superior enterprises have lower requirements on the technology sharing proportion of the other party. Due to its high technology stock and value, it is better able to take risks. Once the other enterprise gets ‘hitchhiking’, the enterprise can also bear the losses caused by the situation. On the contrary, weak enterprises will pay more attention to the technology sharing proportion of the superior enterprises. Only when the proportion is high enough, will be at ease to put technology on the shared platform, to share with the superior enterprises.

6 Conclusions and implications

About the researches of sharing technology just focus on the dominant factors, and few of them can delve into the recessive factors (included time-delay and image factor). In this paper, the explicit and implicit factors are taken into account, and the mathematical model is constructed. We study the evolution process of enterprise technology sharing strategy in technology-intensive innovation ecosystem based on the evolutionary game model, supposing there two kinds of enterprises in the system. Then we discuss the equilibrium strategies under different conditions. Finally, we simulate the process of selecting a technology sharing strategy to study the influence of influencing factors on willingness. According to the game analysis and results, we can summarise as follows:

First, the shorter the time delay of technology transformation, the more likely the enterprise is to conduct technology transaction with other enterprises. This includes sharing technology and acquiring technology from technology innovation platforms. Because if an enterprise’s ability to absorb and adapt to foreign technologies

cannot keep up with the speed of technology flow in the innovation ecosystem, enterprises will not be able to bring expected benefits after sharing technologies with other enterprises, thus reducing their enthusiasm.

Second, the better the impression that the enterprise has made on other participants in the system due to its previous behaviour, the less punishment it will receive in the case of 'hitchhiking'. Because the innovation ecosystem is not immutable, but in the evolution of balance, balance evolution has been in a dynamic state. Moreover, considering the limited rationality and the change of the enterprise's situation, there is no absolute cooperation or non-cooperation among the participants; therefore, the degree of punishment will change with the change of corporate image.

Finally, the proportion of technology sharing that is determined before an enterprise makes a decision critical. Especially for the early stage of the innovation ecosystem, the technology innovation platform is not mature because, at this point, companies are willing to wait-and-see. This is also affected by factors such as the size of decision-making enterprises, technology stock and degree of risk-taking. Enterprises with more technological advantages have lower requirements for other enterprises in decision-making.

In the context of the sharing economy, this study can help the enterprises carry on the strategy choice more clearly and help them more suitable to compete in the mode of innovation ecosystem. Also, some limited aspects should be considered in the future work. We will continue our exploration in the next step.

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Data availability: The dataset used to support the findings of this study is included with in the article.

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References

- [1] Chesbrough H.(2006), Open Business Models: How to Thrive in the New Innovation Landscape. Boston: Harvard Business School Press.
- [2] X.W. Cui, X.N. Wu.(2016), Analysis on the Evolution of Industrial Technology Innovation Mode. Forum on Science and Technology in China. 5(1), 31-37;
- [3] C.L Wu, Y.H Wang.(2013), Review of Studies on the Ecosystem of Industrial Technology Innovation. Science of Science and Management of S.& T. 10(7), 113-121;
- [4] Z.Q Shi, R.L Cai, X.Q Zhu.(2017), Research on Innovation of Intelligent Production Sharing Business Model. China Soft Science. 6, 130-139;
- [5] H.Y Li, Juan S.(2014), A Case-Study of Resource Integration and its Evolution in the Ecosystem of New Technology Innovation. China Soft Science. 6,129-141;
- [6] J. Chen.(2011), Research on the Self-organizing Operation Mechanism of Science and Technology Resource Sharing System. Harbin: Harbin Engineering University;
- [7] G. Zhang, K. Wen, X.P Song et al.(2018), Innovation Ecosystem: Theory and Practice. Beijing: Economic Management Press;
- [8] S.W Cheng.(2014), Deepening Reform will be Driven by Institutional Innovation. China Soft Science. 1, 1-5;
- [9] Q.D Chen.(2018), The Practice and System Value of Patent Open License from the Perspective of Sharing Economy. Forum on Science and Technology in China. 11, 86-93;
- [10] Y Chen, F.G Xie, X.Y Yu et al.(2018), The Influencing Factors and Route Selection of the Niche Evolution of Strategic Emerging Industries. Systems Engineering-Theory Methodology Application. 27(3), 414-421+451;
- [11] L.M Zhao, J.H Sun, H.B Zhang.(2017), Research on Technology Sharing Behavior of Civil-military Integrated Collaborative Innovation System based on Differential Game. Journal of Industrial Engineering and Engineering Management. 31(3), 183-191;
- [12] M.Y Wang, L.J Xiao, Ling W.(2018), Research on the Incentive Mechanism of Cooperative Sharing of Strategic Emerging Industries based on Evolutionary Game. Journal of Industrial Engineering and Engineering Management. 32(3), 206-213;
- [13] R.H Wang.(2016), The Evolutionary Game of Knowledge Sharing in Innovation Organizations. Operations Research

- and Management Science. 25(4), 31-38;
- [14] Ho S P, Hsu Y, Lin E.(2011), Model for Knowledge-sharing Strategies: a Game Theory Analysis. *Engineering Project Organization Journal*. 1(1), 53-65;
 - [15] Dan X, Y.W Zhou, Y.G Zhong et al.(2017), Competition and Cooperation Game Research on Inventory Technology Sharing Retailer Joint Purchasing Alliance under Stochastic Demand. *Journal of Industrial Engineering and Engineering Management*. 31(4), 194-199;
 - [16] Shen Z X, S.Y Y. (2014), Financial Payoff in Patent Alliance: Evolutionary Dynamics Modeling. *IEEE Transactions on Engineering Management*. 61(4), 730-737;
 - [17] X.Y Zhao.(2019), Patent or Technical Secret-Research on Innovation Protection Strategy from the Perspective of Evolutionary Game. *Forum on Science and Technology in China*. 3, 124-131;
 - [18] Friedman D.(1998), On Economic Applications of Evolutionary Game Theory. *Journal of Evolutionary Economics*. 8(1), 15-43.
 - [19] Gao, W. and W.F. Wang, The fifth geometric-arithmetic index of bridge graph and carbon nanocones. *JOURNAL OF DIFFERENCE EQUATIONS AND APPLICATIONS*, 2017. 23(1-2SI): p. 100-109.
 - [20] Gao, W., et al., Ontology learning algorithm for similarity measuring and ontology mapping using linear programming. *JOURNAL OF INTELLIGENT & FUZZY SYSTEMS*, 2017. 33(5): p. 3153-3163.
 - [21] Owolabi, K.M. and A. Atangana, Chaotic behaviour in system of noninteger-order ordinary differential equations. *CHAOS SOLITONS & FRACTALS*, 2018. 115: p. 362-370.
 - [22] Alkahtani, B.S.T., A. Atangana and I. Koca, New nonlinear model of population growth. *PLOS ONE*, 2017. 12(e018472810).
 - [23] Atash, A.A. and H.S. Bellehaj, Applications of the Generalized Kummer's Summation Theorem to Transformation Formulas and Generating Functions. *Applied Mathematics & Nonlinear Sciences*, 2018. 3(2): p. 331–338.
 - [24] Devaki, P., et al., Wall Properties and Slip Consequences on Peristaltic Transport of a Casson Liquid in a Flexible Channel with Heat Transfer. *Applied Mathematics & Nonlinear Sciences*, 2018. 3(1): p. 277–290.