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Original Research

Research on Technology Transfer Strategy of Digital Economy Enabling Green Innovation System

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Abstract

The transfer of technology in the green innovation system is a process that promotes the delivery of environmentally friendly technologies from developers to users. However, under the background of the digital economy, conducting green innovation cooperation to promote technology transfer is an important issue facing the high-quality development of the green innovation system. This paper, based on the construction of the mechanism for technology transfer in the green innovation system empowered by the digital economy and based on the principles of bounded rationality and profit maximization, uses evolutionary game theory to analyze the relationships of technology transfer among multiple entities within Xiaomi Technology Co., Ltd.'s green innovation ecosystem and to explore the impact and strategic choice of sharing willingness intensity on technology transfer between innovative entities. The research results show that: (1) In green innovation activities, various innovative entities (such as research institutions, universities, enterprises, etc.) and technology transfer carriers (such as innovation platforms, innovation ecosystems, policies, etc.) play important roles. Through the empowerment of the digital economy, the enthusiasm of these entities and carriers can be fully mobilized to promote the development of the green innovation system. (2) Under the influence of businesses' pursuit of maximum profit strategies, there is a negative correlation between the intensity of sharing willingness and cooperation time among businesses within the green innovation ecosystem. By adjusting the threshold intensity of sharing willingness, it was found that the trust crisis in technology transfer could be postponed. (3) There is a positive correlation between the intensity of sharing willingness and the time of collaborative cooperation between businesses and academic research institutions within the green innovation system. By enhancing the threshold intensity of sharing willingness, the evolution of technology transfer will show an increasing trend over time. This study promotes the development of green innovation activities from the perspective of knowledge sharing in collaborative innovation

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empowered by digitization, providing theoretical references for the green innovation system to achieve high-level technology transfer.

Keywords: digital economy, green innovation system, technology transfer, evolutionary game, sustainable development

Introduction

The development of the digital economy has become a global consensus. With the promotion of new generation information technologies such as the Internet of Things, big data, artificial intelligence, and blockchain, it has entered a "nuclear fusion"-type explosion stage. These technologies are providing powerful tools to promote the development of green innovation activities in unprecedented ways, offering possibilities for building a more effective and inclusive green innovation system [1]. Under the dual pressures of environmental protection and economic development, the supply and demand of green technology transfer have shown systemic evolution. This means that research institutions, universities, enterprises, and other innovative entities need to collaborate to achieve effective transfer of green technology. In this process, digitization can provide strong support. For example, by using digital platforms, innovators can conveniently exchange information and share resources, thus accelerating the process of green technology transfer [2]. In the digital economy, information and knowledge can be shared instantly, which helps promote the dissemination and application of green technology, allowing more businesses and individuals to timely acquire and use new technology, speeding up the transformation of green technology achievements into commercial value [3]. The level of digital economy development affects the development and application of green technology. Regions with high digital capabilities, such as Silicon Valley and Shenzhen, can integrate the latest information and communication technology, AI technology, and big data technology to create more efficient and environmentally friendly solutions. Regions where the digital economy is developing slowly, however, need to increase their green innovation capabilities by introducing external technology and knowledge [4].

Additionally, the transfer of green technology not only promotes environmental concepts and practices globally but also introduces new information communication technology, big data technology, artificial intelligence technology, etc., to various countries and regions. In the process of green technology transfer, big data can help companies better understand market demand, predict future trends, make more scientific decisions, create conditions for the development of the digital economy, and inject new vitality into its development [5]. Therefore, the digital economy and green technology transfer complement each other, jointly promoting high-quality economic and social development. Due to regional differences in the supply-demand relationship for green innovation resources and the level of digital economy development, the development and application of green technology often show significant regional distribution. This provides a foundation for the transfer of green technology and is of great significance for narrowing the development gap between regions and achieving global sustainable development [6]. In the process of digital economy development, the application value of green technology can be presented in non-physical forms such as graphics, skills, and methods without affecting the transferrer's ownership of the technology [7], thereby facilitating technology transactions and innovation and protecting the rights of technology owners.

With the rapid development and widespread application of green technology, it now plays a leading role in various industries. However, some enterprises may encounter phenomena such as "do not want to, dare not, do not know how to" conduct green innovation activities against the background of the digital economy. The development of China's digital economy in recent years has indeed promoted the annual growth of the contract transaction volume of green technologies [8]. Although the total amount of green technology achievements' transformation and transfer is rapidly increasing, China's conversion rate is still relatively low [9]. The technology achievement conversion rate of developed Western countries has already reached about 70%, while that of China is less than 30%, which is far from comparable. To complete the transfer and transformation of green technology achievements under the development environment of the digital economy, further strengthening of collaborative innovation among industry, academia, and research is needed to promote effective linkage between knowledge, skills, and resources. The close cooperation between businesses, universities, and research institutions can ensure the efficient application of technological innovations and their transformation into real economic value. Therefore, it is imperative to promote the digital construction of green technology and achievement transfer.

Theoretical Basis and Literature Review

Technology Transfer System

The concept of "technology transfer" was first proposed at the United Nations Conference on Trade and Development in 1964. Since the 1980s, the theory of technology transfer systems has been widely discussed by governments, universities, and enterprises around the world. Yu et al. [10] believed that technology transfer is the transfer from one place to another. In different countries, regions, industries, enterprises, and other fields, people and information are used as carriers to carry out the input and output of technical knowledge. At present, scholars' research on technology transfer systems mainly revolves around the following two levels: First of all, relevant research is carried out around its connotation and function. Carayannis et al. [11] explored the development process of the theoretical system, policies, and practices of technology transfer. However, Barros et al. [12] reviewed the literature from 2013 to 2018 and found that most of the coupling relationship between knowledge management and technology transfer occurred in the private sector, and academic and research institutions were an important force to stimulate industrial technology transfer. System regulation of technology transfer can be realized through university-enterprise R&D cooperation [13]. This creates a dynamic equilibrium relationship between independent innovation, technology transfer, and economic growth. From a market-oriented perspective, the effect on short-term economic growth is not significant, but it has a significant effect on long-term economic growth [14]. Wang et al. [15] believed that there is still room for further exploration in the development of China's technology transfer system, pointing out that the development law of China's technology transfer system shows a trend of functional separation from the initial stage to the development stage of functional integration, and then to the mature stage of functional collaborative evolution.

In addition, based on the relevant research on domestic and international technology transfer systems, Wei [16] believed that China urgently needs to promote changes in technology legislation as soon as possible in order to promote the evolution of China's technology transfer system towards an ecosystem. And with the development of heterogeneity in the technology transfer system, China's technology transfer institutions are becoming increasingly specialized [17]. As an important carrier of technology transformation, the technology market is an important part of China's technology transfer system. Qiu [18] emphasized that the development of China's technology transfer system should be strengthened from the perspectives of the technology supply side, market standardization, institutional guarantee, and strengthening talent support. Taking the international technology transfer experience of typical countries (regions) such as the United States, the European Union, Southeast Asia, and the Middle East as inspiration, it can provide important insights for the development of China's technology transfer system [19]. Töpfer et al. [20] analyzed the structural dynamics of the German cluster innovation network, forming a technology transfer system that affects other enterprises in the cluster through government support for a central enterprise. Of course, due to the significant impact of social technology on the success of technology transfer systems, the technology transferred by developed countries needs to be modified in order to be promoted and applied in specific developing countries [21]. Through smooth technology transfer channels, economic circulation and development will be promoted. Yu et al. [22] incorporated public expectations and expert guidance into the model to study the impact of technology transfer on the economic circulation model from the perspective of the resource base and concluded that technological cooperation, digital capacity development, technology sharing, and stakeholder participation are the core influencing factors for realizing technology transfer.

Digital Innovation Ecosystem

Digital empowerment has broken through the traditional unidirectional linear 'chain innovation' process of green innovation from knowledge accumulation, basic research, and applied research [23]. Many scholars at home and abroad have shown that the transformation of the innovation ecosystem towards digitalization has taken on a new organizational form [24]. Digital empowerment has promoted the overall evolution of the green innovation system to a higher level of value creation, integrating multi-dimensional aspects such as innovation, ecological space, resources, functions, and relationships, realizing the leap in technological innovation capabilities [25]. With the development of digitalization, networking, and intelligent technologies, the fourth industrial revolution represented by the new generation of information technology is rapidly rising; many enterprises have built digital innovation ecosystems in the process of carrying out green innovation activities, such as Alibaba's e-commerce innovation ecosystem, Huawei's HarmonyOS application innovation center, Baidu's Apollo autonomous driving innovation ecosystem platform, et al. [26]. Corporate green innovation needs to use digital logic, driven by existing digital technology and empowered by the digital innovation ecosystem, proactively cutting into the industries where the companies are located to achieve green innovation [27].

As the digital innovation ecosystem becomes richer, it promotes resource flow and exchange through open innovation ecology, realizes data openness in an ecological way, fully releases the value of data elements, and promotes the orderly opening of green resources [28]. Focusing on the real scenario requirements of the co-development of multiple innovative entities, relying on the role of digital empowerment, promoting the deep integration of the Internet, big data, artificial intelligence, and corporate green innovation, and providing development plans for green innovation systems in enterprise R&D design, production manufacturing, operation and maintenance, and business management. At the same time, digitization empowers green innovation, which can deepen innovative cooperation among enterprises, universities, research institutions, and governments, and promote cross-border communication and collaboration using digital technology, accelerating the networking and system integration of the green technology innovation process [29]. Therefore, digital empowerment of green innovation is conducive to enhancing the concentration of green innovation and promoting the realization of knowledge and value in the innovative green system.

Existing Research Gaps and Insights

Existing research on the evolution law of knowledge diffusion in digital innovation ecosystems, collaborative innovation, multi-subject technology diffusion, and other studies is relatively abundant, but there are the following shortcomings: (1) Multi-subject technology transfer in the scenario of digital innovation ecosystems presents new features, but few studies have explored the specific impacts of digital innovation ecosystems and have not yet analyzed the impact relationship and operation mechanism in depth with specific cases. (2) Multi-subject technology transfer considers the collaboration and matching between core enterprises and other subjects, but the existing literature does not explore the interactive behavior of multi-subjects in depth and lacks the comprehensive operation mechanism of system integration, which limits the theoretical explanatory ability to a certain extent. (3) Multi-subject technology transfer relies on the diffusion of knowledge in the system; the existing research is mostly carried out from a single perspective, such as the perspective of resource sharing, and does not fully take into account the synergistic role of multiple elements in the ecosystem. With the development of digital innovation ecosystems, the flow of resources and technology sharing is more frequent, the main body of cooperation is closer, the efficiency of innovation is significantly improved, and then building the knowledge diffusion game model to study the transfer of technology is a better framework. In view of this, this paper takes Xiaomi's digital innovation ecosystem as a case object and constructs a game model based on knowledge diffusion to carry out research on the coordination and management of multi-subject technology transfer.

Technology Transfer Mechanism Construction

At present, one of the most notable features of the global digital economy era is that digital technology has accelerated the creation and transfer of knowledge. In the green innovation system, although green technology transfer activities are relatively active, there is still room to improve efficiency. Through digital technology empowerment, the green innovation system can achieve transformations in consultation, service, transfer, development, etc., thereby promoting technology transfer in the digital economy era. According to the characteristics of digital technology, information data within the green innovation system can be connected in real time with information database resources such as patents, achievements, demands, experts, policies, et al., to realize the docking and sharing of green innovation resources. This mechanism helps researchers quickly and accurately gain access to market demand information, shorten green technology transfer links, and improve transfer efficiency. In the process of green technology transfer, if the application of a certain technology is narrow, it may be subject to a certain degree of conscious control for transfer and assignment; if the market demand for green technology is large, efforts will be made to promote it as much as possible, and the supply and demand sides will engage in competitive cooperation. To ensure the benefits of both parties, under the arrangement of government systems, the enthusiasm of various innovative entities and technology transfer carriers can be mobilized, and coordination, guidance, and coordination of technology transfer among members of the green innovation system can be strengthened, guiding the marketization and standardization of technology transfer and improving the digital level of the green innovation system. At the same time, the green technology transfer mechanism needs to be based on the real requirements of the market.

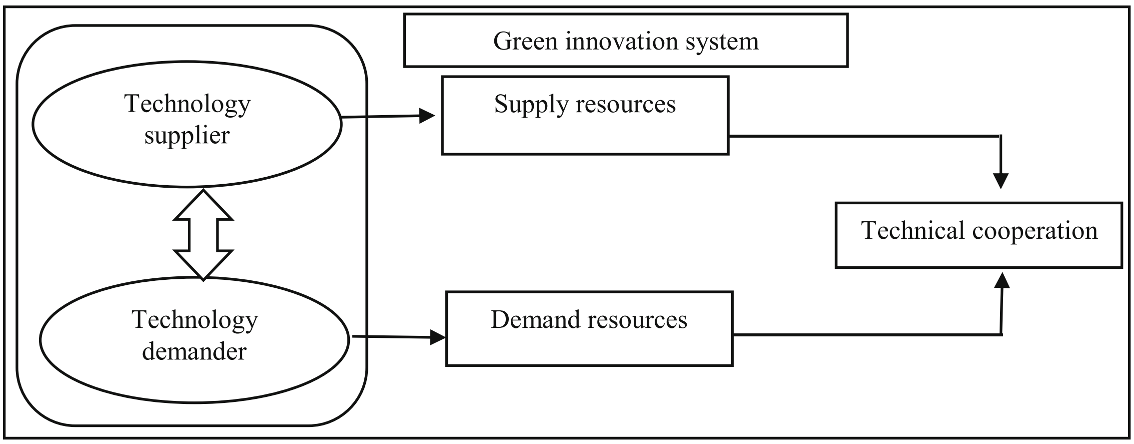

Fig. 1. Technology transfer mechanisms of the digital economy enabling green innovation system.

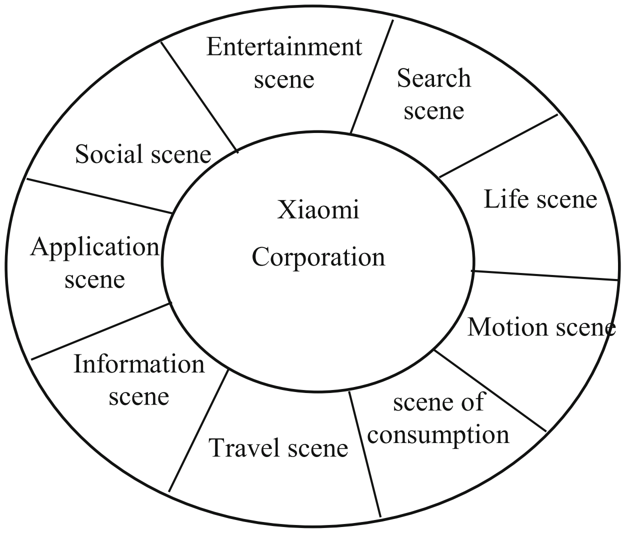

Fig. 2. The digital economy empowers Xiaomi's green innovation system.

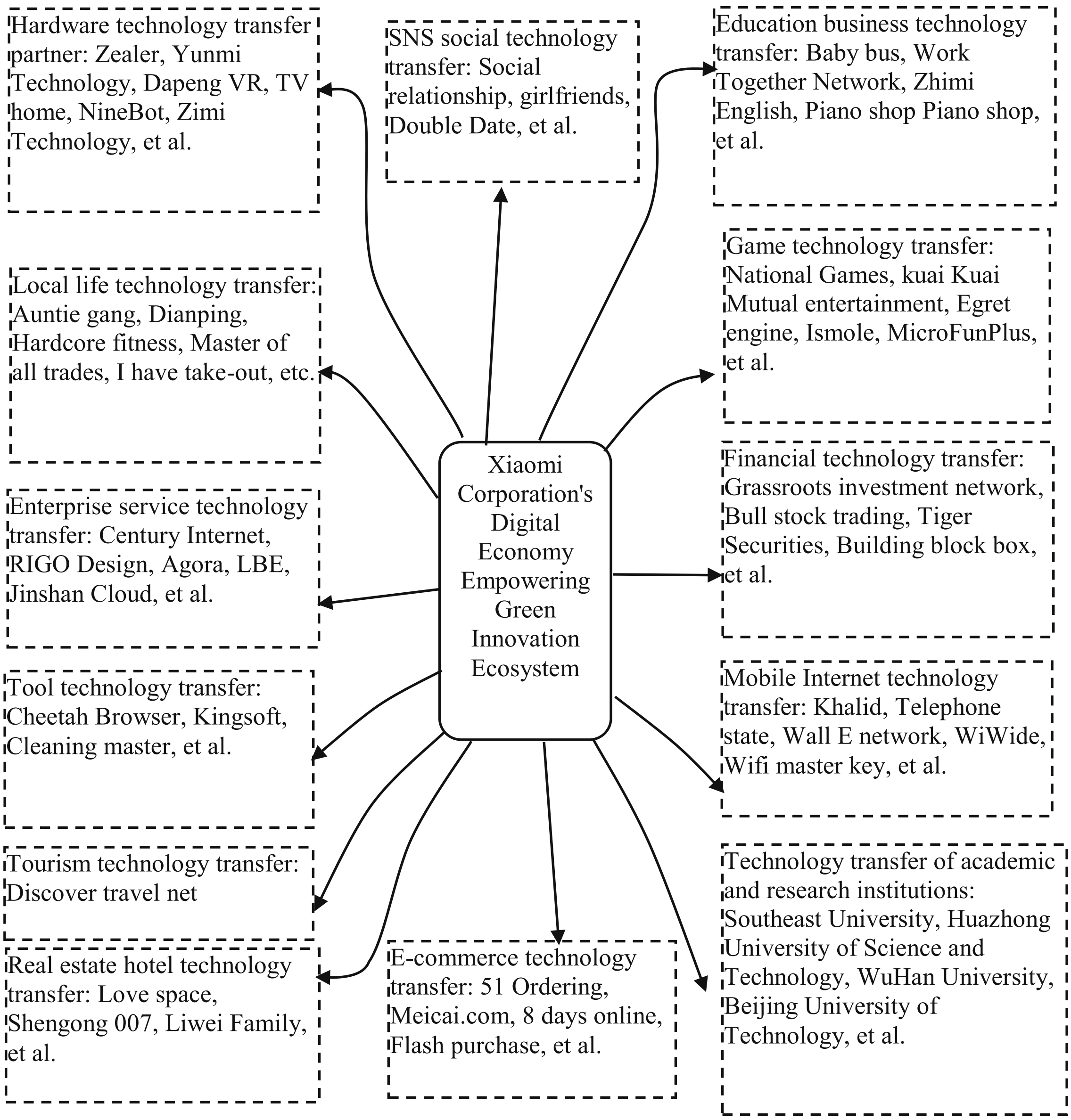

Fig. 3. Technology transfer context of the digital economy enabling Xiaomi's green innovation system.

By using digital technology to portray enterprises, match appropriate technology supply resources and policies, etc., the development of green technology transfer can be sped up. This interaction enhances system efficiency through the role of digital empowerment, promotes information sharing and cooperative innovation among innovative entities, and drives the application and diffusion of green innovation results. The details are shown in Fig. 1.

Description of the Problem

Xiaomi Technology Limited Liability Company (hereinafter referred to as Xiaomi) was established in 2010, launching the inaugural beta version of MIUI. Since implementing the Green Innovation Ecosystem Plan in 2013, Xiaomi has rapidly advanced in digital empowerment for green innovation systems. By 2016, the number of companies within the system had reached 55, and by 2021, the number of members within the Green Innovation Ecosystem had grown to

89. As of 2022, through the system's technological transfer, it has catalyzed 22 companies to go public, incubating 19 unicorns. At present, Xiaomi's Green Innovation Ecosystem boasts a technical support team of approximately 6000 people. Xiaomi has established a completely open R&D environment through "Internet +". Its primary method involves utilizing internet forums, Weibo, WeChat, and other social tools to deeply understand user needs, steering the direction of technological transfer within the Green Innovation Ecosystem to make products more user-friendly. Simultaneously, by analyzing users' online order data, market demand information can be promptly obtained, then collaborated with the world's most outstanding factories to produce high-quality products. In the process of digitally empowering the Green Innovation Ecosystem, Xiaomi's digital resources include application distribution, information flow, video patches, opening screens, banners, OTT, and other forms. To accommodate the development needs of the digital economy, Xiaomi has proposed a variety of application scenarios, such as entertainment, life, consumption, information, travel, applications, social, and so on. These scenarios not only enrich users' personal knowledge graphs but also provide diverse data support for technology transfer, including basic features, user intentions, geographical location, etc., as shown in Fig. 2.

In general, Xiaomi innovatively constructs an efficient technology transfer system by integrating and utilizing various digital resources. In the digital economy, Xiaomi's Green Innovation Ecosystem can be described as a data warehouse that integrates scattered data from multiple parties in the Xiaomi ecosystem.

Through digitalization-enabling tech standardization, it promotes the formation of an organic, mutually beneficial, self-growing ecosystem within the Green Innovation Ecosystem. In terms of technological collaboration, Xiaomi provides technical support for the green innovation ecosystem members to carry out co-design and R&D products through hardware product design patents and technology patents, as depicted in Fig. 3.

Model Construction

Game Model of Technology Transfer Between Xiaomi and Partner Enterprises

a. Model hypothesis

Hypothesis 1: Xiaomi can effectively promote the realization of national strategic needs, industry leadership, and user centrism through joint technology breakthroughs and green technology sharing. This method not only promotes the development of green innovation activities but also facilitates the transfer of green technology.

Hypothesis 2: From the perspective of bounded rationality, Xiaomi will tend to choose the option that maximizes benefits when faced with multiple choices. This may lead them to choose the green technology that maximizes their own interests for transfer during green innovation activities.

Hypothesis 3: Combining evolutionary game theory, Xiaomi will continuously adjust and optimize their strategies in the process of green innovation activities, seeking to maximize benefits while trying to find the best combination of strategies to achieve their goals.

Hypothesis 4: In the face of the laws of digital economy development, Xiaomi's green innovation activities and their results will be influenced by the market environment and competitive situation, necessitating adaptation and optimization of its innovation strategy.

These hypotheses provide a framework that can be used to explore in depth the strategies and methods of Xiaomi's green innovation activities against the backdrop of the digital economy. The specific parameter settings are as follows:

(1) Let Xiaomi be denoted as A_1. The collaborative innovation enterprise is A_2.

(2) There are two choices in the collaborative innovation process of A_1 and A_2 technology sharing and non-sharing. The technical resources of A_1 and A_2 are H_1 and H_2. The resource prices before sharing are P_1 and P_2, $P_1>P_2>0$.

(3) The degree of resource sharing between A_1 and A_2 is α and β. L_1 and L_2 are resource income distribution coefficients. The green innovation system, constituted by A_1 and A_2, has facilitated technology transfer through the sharing of resources, yielding the respective benefits of $L_1H_1^{\alpha}H_2^{\beta}$ and $L_2H_1^{\alpha}H_2^{\beta}$.

(4) The cost of resource sharing for A_1 and A2 is C_1 and C_2 respectively.

Table 1. Game payoff matrix.

	A_2		
	Strategy	Share (y)	Unshared (1-y)
A1	Share (x)	$P_1\left(H_1 - H_1^{\acute{a}}\right) - C_1 + L_1 H_1^{\acute{a}} H_2^{\hat{a}}$, $P_2\left(H_2 - H_2^{\acute{a}}\right) - C_2 + L_2 H_1^{\acute{a}} H_2^{\hat{a}}$	$P_1 H_1 + F_1 - C_1$, $p_2 H_2 - F_1 + p_1 H_1^{\alpha}$
	Unshared (1-x)	$P_1 H_1 - F_2 + P_2 H_2^{\hat{a}}$, $P_2 H_2 + F_2 - C_2$	$P_1 H_1$, $P_2 H_2$

Table 2. ESS stability judgment.

Strategy point	Jacobian characteristic roots and symbols	Value and symbol of trace	Status
(0,0)	$(F_1 - C_1)(F_2 - C_2)$ +	$[(F_1 - C_1) + (F_2 - C_2)]$ -	ESS
(0,1)	$(L_1 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} + P_2 H_2^{\beta} + F_2 - C_1)(C_2 - F_2)$ +	$L_1 H_1^{\alpha} H_2^{\beta} - P_a H_1^{\alpha} + P_b H_2^{\beta} - C_1 + C_2$?	Unstable
(1,0)	$(L_2 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} + P_2 H_2^{\beta} + F_1 - C_2)(C_1 - F_1)$ +	$(L_2 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} + P_2 H_2^{\beta} - C_2 + C_1$?	Unstable
(1,1)	$(L_1 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} + P_2 H_2^{\beta} + F_2 - C_1)(L_2 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} + P_2 H_2^{\beta} + F_1 - C_2)$ +	$-(L_1 H_1^{\alpha} H_2^{\beta} - 2P_1 H_1^{\alpha} + 2P_2 H_2^{\beta} + F_2 - C_1) - (L_2 H_1^{\alpha} H_2^{\beta} + F_1 - C_2)$ -	ESS
$\left(\frac{C_2 - F_2}{L_2 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} - P_2 H_2^{\beta} + F_1 - F_2}, \frac{C_1 - F_a}{L_1 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} - P_2 H_2^{\beta} + F_2 - F_1}\right)$			Saddle point

(5) If A_1 shares and A_2 does not share, A_2 gets extra revenue of $p_2 H_2^{\beta}$. Similarly, if A_2 shares and A_1 does not share, A_1 can obtain additional revenue $p_1 H_1^{\alpha}$. Of course, A_1 and A_2 have certain unknown risks in the process of cooperative innovation, and the risk factor is F_1 and F_2. The payoff matrix for A_1 and A_2 is shown in Table 1.

b. Model solution

Let's assume that the return of A_1 is E_1 when it is shared and E_2 when it is not shared:

$$E_1 = yL_1 H_1^{\alpha} H_2^{\beta} - yP_1 H_1^{\alpha} + P_1 H_1 + (1-y)F_1 - C_1 \quad (1)$$

$$E_2 = yP_2 H_1^{\alpha} - yP_2 + P_1 H_1 \quad (2)$$

A_1 income can be obtained:

$$EA = x[yL_1 H_1^{\alpha} H_2^{\beta} - yP_1 H_1^{\alpha} + P_1 H_1 + (1-y)F_1 - C_1] + (1-x)\left(yP_2 H_2^{\beta} - yF_2 + P_1 H_1\right) \quad (3)$$

Then the replication dynamic equation of A_1 is:

$$F(x) = \frac{dx}{dt} = x(1-x)\left[y\left(L_1 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} - P_2 H_2^{\beta} + F_1\right) - F_2 - C_1\right] \quad (4)$$

Similarly, the replication dynamic equation of A_2 is:

$$F(y) = \frac{dy}{dt} = y(1-y)\left[x\left(L_a - P_1 H_1^{\alpha} - P_2 H_2^{\beta} + F_1 - F_2\right) + F_2 - C_2\right] \quad (5)$$

According to the stability principle of the replicated dynamic differential equation and the properties of the evolutionary stability strategy, the points of evolutionary stability are (0,0), (0,1), (1,0), (1,1).

$$\left(\frac{C_2 - F_2}{L_1 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} - P_2 H_2^{\beta} + F_1 - F_2}, \frac{C_1 - F_1}{L_1 H_1^{\alpha} H_2^{\beta} - P_1 H_1^{\alpha} - P_2 H_2^{\beta} + F_2 - F_1}\right)$$

The Jacobian matrix can be used to analyze its stability as shown in Table 2.

Table 3. Simulation parameter assignment.

Variable	F_1	F_2	H_1	L_1	L_2	α	β	P_1	P_2	C_1	C_2
Value	0.6	0.4	7	0.6	0.4	0.5	0.4	6	2	3	1

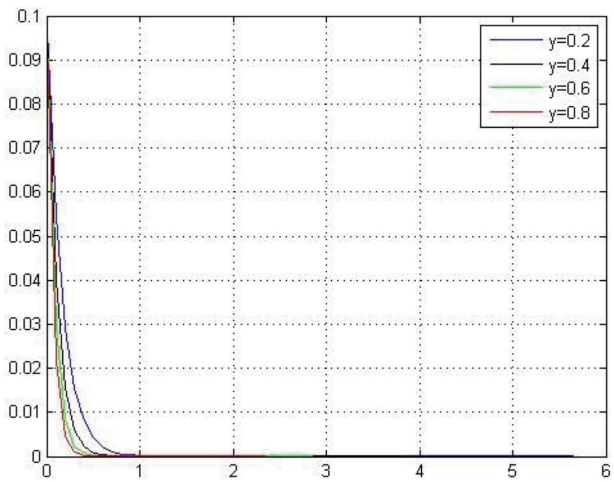

Fig. 4. Time dependent variation of y at x = 0.1.

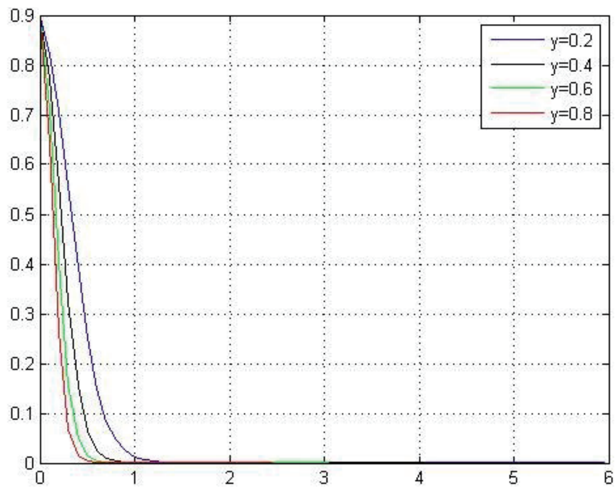

Fig. 5. Time dependent variation of y at x = 0.1.

As can be deduced from Table 2, only the points (0,0) and (1,1) represent ESS states; that is, within the green innovation system, the choice of enterprises to either share technology or refrain from doing so constitutes a Nash equilibrium.

c. Simulation analysis

In this paper, Matlab software is used to analyze the built model. According to the research results of He et al. [30], the simulation is assigned as shown in Table 3.

Firstly, this study fixes the changing x values and sets x = 0.1 and x = 0.9, respectively, representing A_1's unshared and shared states. The y threshold is set at 0.2, 0.4, 0.6, and 0.8, respectively, corresponding to the size of A_2's sharing tendency. The details are shown in Figs. 4-5. Fig. 4 shows that A_1 has a higher tendency not to share when x = 0.1. The y threshold is set at 0.2, 0.4, 0.6, and 0.8, respectively, corresponding to the size of A_2's sharing tendency. That is, the larger the value of y, the slower the decline trend will be. If A_1 chooses not to share, then the optimal strategy for A_2 is to also not share resources. Thus, the equilibrium point of the game between both sides is stable at (0,0). As shown in Fig. 5, A_1 has a higher tendency to share when x = 0.9. The relationship between the changes in the image of y and time shows a positive correlation, meaning the longer the cooperation time, the more obvious the degree of image degradation. A_2 prefers sharing strategies, which can yield more benefits. At this point, the equilibrium point of the game between the two parties is (1,1).

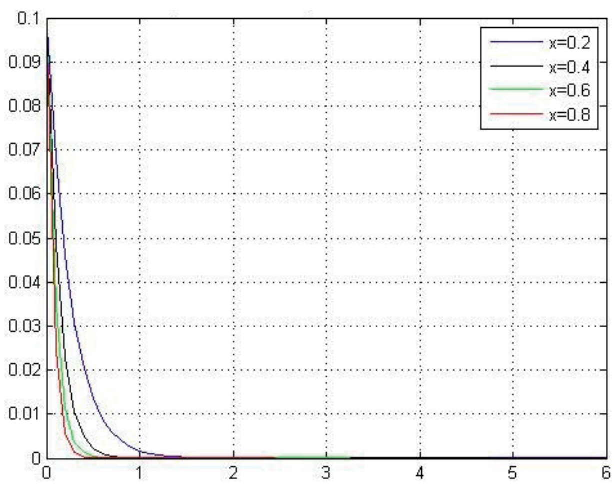

Fig. 6. Time dependent variation of x at y = 0.1.

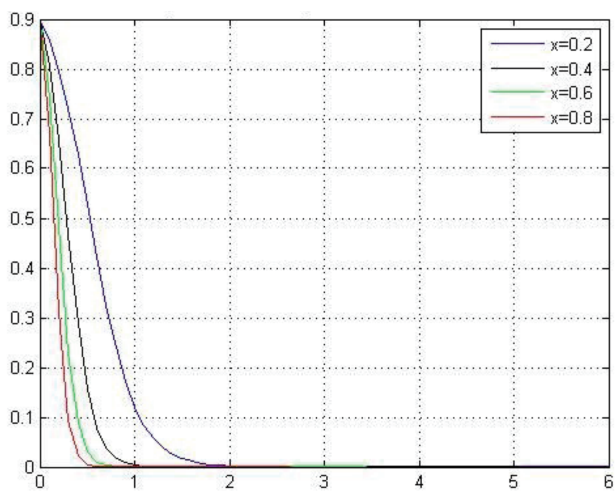

Fig. 7. Time dependent variation of x at y = 0.9.

Table 4. Game payoff matrix.

		A_1	
	Strategy	High-level collaboration (y)	Low-level collaboration (1-y)
A_3	High-level collaboration (x)	ωI_4-C_4, υI_4-C_6	ωI_3-C_4, υI_3-C_5
	Low-level collaboration (1-x)	ωI_2-C_3, υI_2-C_6	ωI_1-C_3, υI_1-C_5

Similarly, when y = 0.1 and y = 0.9, they represent A_2 unshared and shared states. The x threshold is set at 0.2, 0.4, 0.6 and 0.8, which respectively correspond to the size of the A_1 sharing tendency. The details are shown in Figs. 6-7. Fig. 6 shows that when y = 0.1, A_2 has a higher non-sharing tendency. The threshold changes of y, under the strategic goal of maximizing profits pursued by the enterprise, becomes more severe as the threshold increases over time. At this point, the optimal strategy for A_1 is not to share. Therefore, the equilibrium point of the game between both parties is stable at (0,0). Similarly, in Fig. 7, when y = 0.9, A_2 has a higher sharing tendency, and A_1 tends to choose the sharing strategy. The equilibrium point of the game is (1,1). Combining the sharply declining image trajectories in Figs. 6-7, it is necessary to comprehensively consider the game relationship between both parties. In the green innovation system, both parties are prone to trust crises and the risk of technology leakage during the cooperation process. At this time, the optimal strategy of both parties in the initial cooperative innovation is (1,1). With the passage of time, the distrust between the two parties increases, and the optimal strategy becomes (0,0). The above simulation process further verifies the inference of the game model.

Technology Transfer Game between Xiaomi and Academic and Research Institutions

a. Game hypothesis

Hypothesis 1: Xiaomi and academic research institutions can more effectively promote the development of the green innovation system through collaborative innovation. This type of collaborative innovation not only promotes technology transfer but also improves R&D efficiency and innovation quality.

Hypothesis 2: Xiaomi and academic research institutions, based on bounded rationality, will tend to choose the option that maximizes benefits when faced with multiple options. This may lead them to choose the technology that maximizes their own interests for transfer during the collaborative innovation process.

Hypothesis 3. In the collaborative innovation process of Xiaomi and academic research institutions, evolutionary game theory may play a key role. That is that both parties are always pursuing maximum benefits while trying to find the best strategy combination to achieve this goal.

Hypothesis 4: The evolution and optimization of the green innovation system will depend on how Xiaomi and academic research institutions adjust and optimize their collaborative innovation strategies to adapt to the constantly changing market environment and competitive situation.

The above assumptions will serve as the theoretical foundation and guiding principles of this study. By conducting in-depth analysis and discussion, we hope to provide valuable theoretical and practical guidance for enterprise-academic institution collaborative innovation in the digital economy. The specific parameter settings are as follows:

(1) Xiaomi is represented as A_1 in this study, while academic and research institutions are represented as A_3.

(2) Academic and research institutions have technological research teams and research advantages, while Xiaomi has advantages in the market, information technology, and knowledge. There are two types of cooperative innovation: low-level collaboration and high-level collaboration.

(3) The cost of low-level collaborative innovation is C_3, while the cost of high-level collaborative innovation is C_4.

(4) The cost of low-level collaborative innovation for the Xiaomi Company is C_5, while the cost of high-level collaborative innovation is C_6.

(5) Both parties choose I_1 for the benefit of low water collaborative innovation, and I_4 for the benefit of high-level collaborative cooperation. The academic and research institutions adopt low-level collaborative cooperation, while Xiaomi adopts high-level collaborative cooperation; the income is I_2. The academic and research institutions adopt high-level cooperation, while Xiaomi adopts low-level cooperation, the income is $I_3(I_4>I_3>I_1, I_4>I_2>I_1)$.

(6) Both parties agree on the content of the technology transfer agreement in advance. In the process of establishing a green innovation system, academic and research institutions can transfer technology to Xiaomi Company. The proportion of benefits distributed by academic and research institutions is ω. The proportion of benefits allocated by Xiaomi Company is υ. $\omega, \upsilon>0$, $\omega + \upsilon = 1$.

Based on the above assumptions, the payoff matrix of the game can be deduced, as shown in Table 4.

b. Model solution

Let the low-level collaborative innovation benefit function for Xiaomi Company be E_4, and the high-level collaborative innovation benefit be E_5.

$$\begin{aligned} E_4 &= y(\omega I_4 - C_3)+(1-y)(\omega I_3 - C_4) \\ &= y\alpha(I_4 - I_3)+\omega I_3 - C_4 \end{aligned} \tag{6}$$

Table 5. ESS stability judgment.

Strategy point	Jacobian characteristic roots and symbols	Value and symbol of trace	Status
(0,0)	$[\omega(I_3 - I_1) + C_3 - C_4]$ $[\upsilon(I_2 - I_1) + C_5 - C_6]$ +	$[\omega(I_3 - I_1) + C_3 - C_4]$ $+[\upsilon(I_2 - I_1) + C_5 - C_6]$ +	Unstable
(0,1)	$-[\omega(I_4 - I_2) + C_3 - C_4]$ $[\upsilon(I_2 - I_1) + C_5 - C_6]$ -	$[\omega(I_4 - I_2) + C_3 - C_4]$ $-[\upsilon(I_2 - I_1) + C_5 - C_6]$?	Unstable
(1,0)	$-[\omega(I_3 - I_1) + C_3 - C_4]$ $[\upsilon(I_4 - I_3) + C_5 - C_6]$ -	$-[\omega(I_3 - I_1) + C_3 - C_4]$ $+[\upsilon(I_4 - I_3) + C_5 - C_6]$?	Unstable
(1,1)	$[(I_4 - I_2) + C_3 - C_4]$ $[(I_4 - I_2) + C_5 - C_6]$+	$-[(I_4 - I_2) + C_3 - C_4]-$ $[(R_4 - R_2) + C_5 - C_6]$ -	ESS
$\left(\frac{C_4 - C_3 - \omega(I_3 - I_1)}{I_1 - I_3 - I_2 + I_4}, \frac{C_6 - C_5 - \upsilon(I_2 - I_1)}{\upsilon(I_1 - I_3 - I_2 + I_4)}\right)$			Saddle point

$$W(x) = \frac{dx}{dt} = x(1 - x)[y\omega(I_4 + I_1 - I_2 - I_3) + \omega(I_3 - I_1) + C_3 - C_4] \quad (7)$$

Therefore, the replication dynamic equation W(x) of the Xiaomi Company is:

$$W(x) = \frac{dx}{dt} = x(1 - x)[y\omega(I_4 + I_1 - I_2 - I_3) + \omega(I_3 - I_1) + C_3 - C_4] \quad (8)$$

Similarly, the replication dynamic equation W(y) of academic and research institutions is:

$$W(y) = \frac{dx}{dt} = y(1-y)[x\upsilon(I_1 + I_4 - I_3 - I_2) + \upsilon(I_2 - I_1) + C_5 - C_6] \quad (9)$$

According to the stability principle of the replicated dynamic differential equation and the properties of the evolutionary stability strategy, the ESS points of the evolutionary stability strategy are (0,0), (0,1), (1,0), (1,1), $\left(\frac{C_6 - C_5 - \omega(I_2 - I_1)}{I_1 - I_3 - I_2 + I_4}, \frac{C_6 - C_5 - \upsilon(I_2 - I_1)}{\upsilon(I_1 - I_3 - I_2 + I_4)}\right)$.

The stability of formulas (8) and (9) can be analyzed by using the Jacobian matrix, as shown in Table 5.

As can be seen from Table 5, (1,1) becomes the only stable ESS point and the optimal Nash equilibrium solution.

c. Simulation analysis

In this paper, Matlab software is used to analyze the built model. According to the research results of Sun et al. [31], the simulation is assigned as shown in Table 6.

For the convenience of research, the changing x value is fixed. In this paper, the constants x = 0.1 and x = 0.9 respectively represent the low and high synergy states of A_3. The threshold value of y is set at 0.2, 0.4, 0.6 and 0.8, respectively corresponding to the degree of A_1 cooperative cooperation. The details are shown in Figs. 8-9.

From Fig. 8, it can be seen that when x = 0.1, academic and research institutions adopt low-level collaboration. The threshold change of y evolves over time, and the trend of y is positively correlated with the threshold size. At this point, Xiaomi can achieve the maximum benefits by choosing a high-level collaborative cooperation strategy. As can be seen from Fig. 9, when x = 0.9, academic and research institutions adopt high-level collaborative cooperation. The trend of y shows a positive correlation between time and the degree of collaboration. At this point, the Xiaomi Company chooses a high-level collaborative cooperation strategy to maximize profits. In summary, no matter whether x = 0.1 or x = 0.9, Xiaomi's strategy is high-level collaborative cooperation. By comparing the returns in Figs. 8-9, it can be concluded that the Nash equilibrium solution of the game between the two parties is (1,1).

Table 6. Simulation parameter assignment.

Variable	C_3	C_4	C_5	C_6	I_1	I_2	I_3	I_4	ω	υ
Value	1	2	1	2	2	4	3	6	0.5	0.5

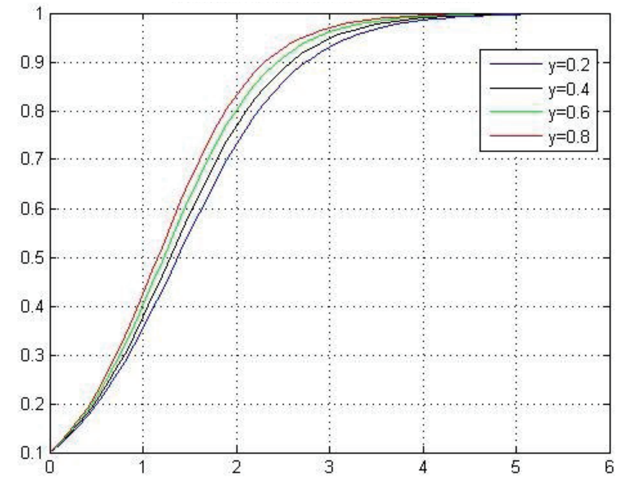

Fig. 8. Time dependent variation of y at x = 0.1.

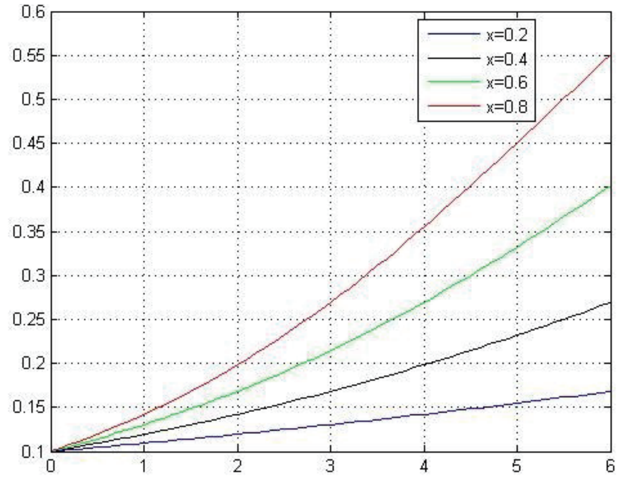

Fig 10. Time dependent variation of x at y = 0.1.

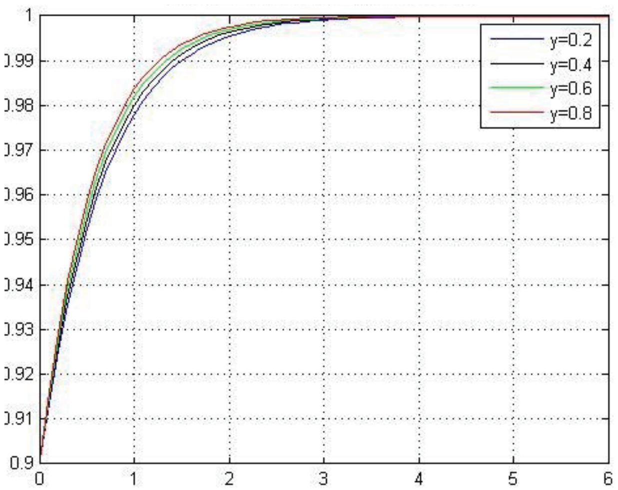

Fig. 9. Time dependent variation of y at x = 0.9.

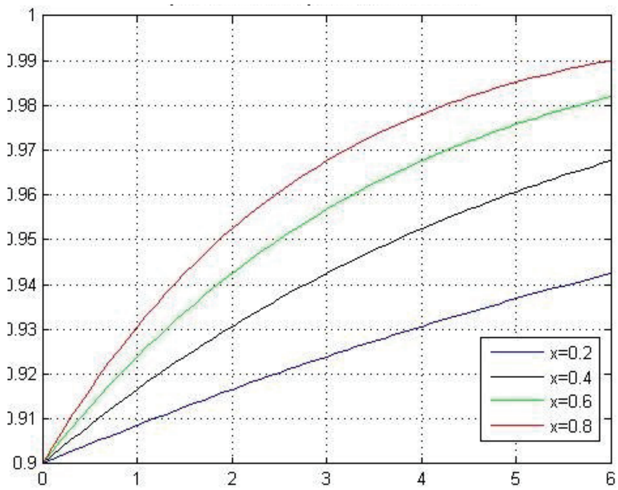

Fig. 11. Time dependent variation of x at y = 0.9.

Similarly, when y = 0.1 and y = 0.9 are set respectively, it represents the low synergy and high synergy states of A_1. The threshold value of x is set at 0.2, 0.4, 0.6 and 0.8, respectively corresponding to the degree of A_3 cooperative cooperation. The details are shown in Figs 10-11.

From Fig. 10, when y = 0.1, the x curve shows a positive correlation between collaborative intensity and time evolution. At this point, academic and research institutions can maximize their benefits by choosing high-level collaboration. In Fig. 11, the trend is similar, and academic and research institutions can also maximize their benefits by choosing high-level collaboration. Therefore, it can be concluded that when y = 0.1 and y = 0.9, the optimal strategies for academic and research institutions are both high-level collaborative cooperation. Based on the above analysis, the Nash equilibrium solution of the game between the two parties is (1,1). These results further validate the derived game model.

Conclusions and Implications

Research Conclusion

In the era of the digital economy, the innovation ecosystem tends towards multi-entity collaborative innovation, which not only accelerates the transfer of digital technology, but also promotes the knowledge flow in aspects such as processes, techniques, and business models under the background of digital technology, forming a strong digital innovative vitality. On the basis of constructing the technology transfer mechanism of the digital economy's empowering green innovation system, this paper explores the impact of technology transfer in the digital economy environment by focusing on the competitive game relationships among multiple entities within Xiaomi's green innovation system. The main conclusions are as follows:

(1) The digital economy empowers the green innovation system to promote the development of technology transfer. Under the environment of

the digital economy, innovators can use the digitization level of the digital technology green innovation system to map the portraits of green innovation entities and match suitable technological achievements, innovation needs, and applicable policies. This fully mobilizes various innovation entities and technology transfer carriers, increases knowledge flow between entities within the system, promotes technology transfer digital links between multiple entities, and thus promotes the continuous development of the green innovation system.

(2) Within the green innovation ecosystem, the intensity of sharing willingness between enterprises and cooperation time shows a negative correlation. It is found that under the influence of businesses pursuing a strategy of maximizing profits, technology transfer behavior within the green innovation system empowered by the digital economy shows a decreasing trend with the development of cooperation time. When one party has a smaller sharing intention, the quality of technology transfer between enterprises will face a trust crisis, causing the cooperation innovation time to shorten. By adjusting the intensity of the sharing willingness threshold, it is found that the trust crisis in green technology transfer is delayed, and the benefits obtained are greater than those with a smaller sharing intention, which can promote the sustainable development of technology transfer in the digital economy.

(3) In the green innovation system, the intensity of sharing willingness between enterprises and academic research institutions and the time of collaborative cooperation show a positive correlation. Research shows that the stronger the resource sharing willingness between enterprises and academic research institutions, the longer the cooperation time between the two parties. This association indicates that in the digital economy environment, thanks to the widespread application of digital technology, the digital economy has improved the accessibility and shareability of information within the green innovation system, thereby accelerating the flow of knowledge between enterprises and academic research institutions and the transfer of green technology. This will contribute to the realization of green technology innovation and environmental sustainability within the green innovation system.

Research Implications

(1) Strengthening the linkage between enterprises and government departments around the transfer and transformation of enterprises' digital innovation technologies. Combined with the actual situation of enterprise green innovation, technology transfer, and transformation, strengthen coordination and optimize process management. At the same time, the government and other relevant departments should strengthen communication between the different enterprises, address the requirements of different enterprises, and formulate specific institutional measures to guide the development of enterprise digital innovation, and to promote the healthy development of the enterprise innovation ecosystem.

(2) Improve the support of financial institutions and information intermediaries for enterprise digital technology transfer. By absorbing the development experience of advanced digital innovation ecosystems and taking into account the actual characteristics of the regions where different enterprises are located, it will formulate special support measures to promote the digital development of enterprises and guide the transfer of financial and information resources to the field of digital innovation.

(3) Establish a sound assessment system for the transfer of enterprise digital innovation technologies and realize the implementation of policies and standardized management of enterprise digital technology transfer and transformation. There should also be a focus on incentivizing government departments to carry out supervision and innovation effect tracking and evaluation to better promote the implementation of policies, as well as giving full play to the role of universities and research institutes in the field of digital innovation to better empower the transfer of digital technology among multiple actors.

Research Gaps and Prospects

The digital innovation ecosystem is a complex system composed of multiple subjects; this paper only considered the game relationship between core enterprises and cooperative enterprises, academic and research institutions, and other subjects in the model, and also only took Xiaomi as the object of research. Therefore, in the future research process, other subjects such as financial institutions and information intermediaries should be added, and more representative enterprises should be used as research objects to analyze the internal mechanisms and laws of technology transfer. In addition, technology transfer is a complex and systematic process, and future research will also explore and analyze the different modes and general laws of technology transfer by combining the perspective of the nature and characteristics of technology transfer with the study of the influencing factors and structure of enterprise digital innovation.

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Conflict of Interest

The authors declare no conflict of interest.

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