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Parasitism or Symbiosis? A Selection of R&D Strategy From the Perspective of Responsibility Paradox

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ABSTRACT The innovation ecosystem advocates both enterprise value and social value. How to make the most beneficial decisions to promote the development of enterprise and system while fulfilling social responsibilities? From the perspective of the paradox of social responsibility, a differential game model of innovation research and development among enterprises in the innovation ecosystem is constructed. The paper analyses the impact of multiple factors on innovation ability and revenue. Including: the subsidy from government, the cost of enterprise and additional benefits from social effect. The conclusions are as follows:(1) Moderate implementation of social responsibility can improve the technical level, social effect and income of innovation system. To achieve the goal of symbiotic evolution of innovation ecosystem, it is recommended that the proportion of core corporate earnings should be higher than one third. (2)For the government, moderate subsidies are very helpful to improve the enthusiasm of technological innovation and social responsibility practice of enterprises. Moreover, the influence on the supporting enterprises (which is in the weak position) is more significant. But the rate needs to be kept within the range of $\left(0, 2/3\right)$. Otherwise it will encourage "free rider" behavior and cause the system to evolve into a parasitic imbalance; (3) The social effect is a positive circular effect. It will increase overall revenue with R&D level of core technology. The interaction between them can promote the symbiotic evolution of the innovation ecosystem;(4) In the symbiotic innovation ecosystem, the profit ratio of core enterprises decreases, but the overall profit value increases.

INDEX TERMS Technology innovation, innovation ecosystem, social responsibility, differential game.

I. INTRODUCTION

The rapid development of network economy and digital economy puts forward higher requirements for the core competitiveness of enterprises. The independent and internalized innovation development mode has been unable to adapt to the increasingly complex scene requirements and technical requirements of abrupt iteration. In order to explore more market opportunities and acquire more external innovation resources, enterprises need to build or join an innovation ecosystem [1], [2]. Some of the world's leading companies (Such as Apple, IBM, Procter & Gamble, Siemens, Microsoft, Google, Haier and so on.) have established dynamic and open innovation ecosystems. These enterprises have produced many highly influential results through resource sharing and information exchanging with other members of the system. It not only improves its own business innovation ability, but also creates value for consumers. Which enterprises can gain market competitive advantage from it. Yet, the establishment of the innovation ecosystem does not guarantee permanent success. Sony and BlackBerry failed to compete with other platform organizations (such as Apple) due to the incompatibility of system members. Nokia lost its first-mover advantage in the end market because of the lack of downstream suppliers. Therefore, it is very important to balance the relationship among participants in the innovation ecosystem.

The ideal innovation ecosystem pursuits mutualism. But the close coordination among players also increases the risk of opportunism. As an integral part of the business model, corporate social responsibility requires companies to be responsible for the consequences of their actions.

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This can effectively reduce the probability of opportunism [3]. Europe's Horizon 2020 research framework mentions "responsible innovation", which emphasis on the interaction between innovation subjects and social actors [4]. It can help to explore the future through collective management of science and innovation [5], [6]. "Responsible innovation" advocates the alignment of the innovation process with social goals. It has increasingly become an innovative governance framework with global influence, especially for developing countries [7], [8]. Collaborative research and development between innovation organizations helps to reduce the cost of innovation and shorten the innovation cycle. But when technology is given the feature of "public good". It will induce enterprises to choose "free rider" opportunistic behavior. This has become the biggest obstacle to technological collaboration between innovative organizations [9]. According to existing researches, trust is a prerequisite for collaborative innovation behavior between organizations. From a process point of view, trust can be given from the past behavior and reputation of organization [10]. Forming a solid reputation is a difficult, expensive and time-consuming process. It needs to be maintained and operated continuously by enterprises. Corporate social responsibility plays a key role in the establishment and maintenance of corporate reputation. This may have an important impact on R&D decisions in the innovation ecosystem.

However, how should enterprises fulfill their social responsibilities? Does over-exercising social responsibility prevent innovation ecosystems from achieving symbiosis?

Social responsibility emphasizes social significance. Therefore, it will cause conflict with enterprise development. Through combing related research, we find there are three types of paradoxes in social responsibility: First of all, the conflict between responsibility and profit. On the one hand, making profits is one of the ways to practice social responsibility. It will promote the economic development process of the whole society. But on the other hand, making profits also means sacrificing the interests of other subjects. The contradiction leads to the paradox about the definition of responsibility boundary [11]. Then, the conflict between responsibility and social desirability. Generally speaking, social responsibility performance is positively correlated with content scope and practice frequency. In other words, that will bring a benign social effects. When enterprises are excessively addicted to the additional benefits which is brought by social responsibility performance, however, may affect the development of core production function of the enterprise. Because the enterprises focus too much on gaining the public attention from social responsibility. If things continue this way, it will lead to excessive blindness of social responsibility practice. The contradiction leads to the paradox about the "moral abduction" [12]. Last but not least, the conflict between responsibility and value creation. Porter believes that the social responsibility paradigm of shared value can truly enable enterprises to achieve value co-creation and value mutual benefit at the level of total economic value and social value [13]. But this is just a beautiful vision. In an innovation system dominated by commercial interests, the incompatibility between business and social goals has not been resolved [14], [15]. Innovation ecosystem is a typical combination of interests. It is rooted in society and serve the community. Each subject in the system is no longer an independent individual, but a part of the system. The core enterprise is the center of strategy and resources in the innovation ecosystem [16], [17]. And it is also the hub of energy transfer and member alternation within the system [18]. The responsibility consciousness of core enterprise directly affects the activities of the system. Therefore, the behavioral decisions of core enterprises are crucial to the innovation ecosystem [19]. It is of great significance to explore the optimal R&D innovation model between core enterprises and supporting enterprises from the perspective of the paradox of social responsibility. Which will help maintain the balance of the innovation ecosystem and promote the sustainable development.

Based on the above analysis, this paper chooses the perspective of the paradox of social responsibility. And the social effect factors will be embedded into the game model of enterprise R&D innovation. When the core enterprise undertakes the main social responsibility and brings convenience to the supporting enterprises, the dependency relationship will arise. So this situation will be abstracted into a Stackelberg master-slave game model. Next, this paper compares various scenarios of R&D. The purpose is to explore the impact of social responsibility on R&D patterns between enterprises in the innovation ecosystem.

II. THEORETICAL BASIS AND REASEARCH FRAMEWORK

A. RESEARCH ON THE INNOVATION RELATIONSHIP AMONG ENTERPRISES IN INNOVATION ECOSYSTEM

Innovation ecosystem is based on three schools: institutional economics, strategic management and innovation management [20]. It advocates symbiotic evolution. Most scholars believe that innovation ecosystem is dominated and established by core enterprises. It will realize the coupling transfer of information flow, material flow and energy flow through the interaction behavior between the core enterprises and others. Finally, multi-win and co-evolution will come true. Existing researches on innovation relationship between enterprises in the system mainly focus on two aspects: (1) Master-slave innovation led by core enterprises. Kun.Q believed that core enterprise plays a great role in promoting the development of innovation ability of the innovation ecosystem. It is a guide and key promoter [21]. Bian [22] and Harland [23] believed that core enterprise has the characteristic of attracting non-core enterprises, and can maximize the technology diffusion and application effect within the innovation network. Yang. M proposed that The industrial chain led by core enterprises provides direction for SMEs. Then they will supporting collaborative innovation with core enterprise [24]. Some scholars put forward conclusions on the interaction of innovation under the leadership of core enterprises. Juan S. proposed that the "non-benign coupling" between core enterprise and members will cause the emergence of "blind spots" in the system [25]. Hu *et al.* [26] believed the management behavior of core enterprise is very important to resolve the contra-diction and promote the stable development of system. The Master-slave innovation will evolve into parasitic innovation once the relationship is unbalanced, which is between core enterprise and others. So relationship is very important for the balance of innovation ecosystem. In addition to related research, the ecological model has also been proved by practice. For example, Huawei built a comprehensive innovation ecosystem of research-exploitation-application. Then, Huawei embedded a competitiveness and cooperation symbiosis mechanism which included share, separate, and overlap resources [27]. In this way, it can achieve breakthroughs in core technology rapidly and efficiently. Therefore the company has established a leading position in the field of related technical products. (2) Symbiotic innovation by decentralized. Lampon found that a "multi-platform" architecture can be used to provide diversified support for different categories of ecosystem marginal actors [28]–[30]. That is to use the "core integration" thinking to replace the "core leading" thinking. Many scholars have begun to think: How can platform enterprises reflect social value and create a symbiotic win-win value sharing relationship with stakehoders? Borrowing from modularization theory and the "plug and play" way of PC system [31], Simon put forward the concept of "ultra-modular systems" for the first time. He emphasized that the interface between the modules presented a structural state of "interweaving" in this systems. It has the characterize of "emergence". Shuai Z. also found that the ultimate innovation ecosystem will gradually evolve into a super modular system structure guided by the open market mechanism [32]. Finally, symbiotic evolution is come true.

B. RESEARCH ON THE INFLUENCE OF SOCIAL RESPONSIBILITY PARADOX ON DEVELOPMENT OF ENTERPRISES

Enterprise innovation not only needs the resource knowledge from itself, but also needs all kinds of external dominant and recessive knowledge. Knowledge is often embedded in innovation networks between enterprises and their partners, such as universities and research institutes. If an enterprise wants to acquire and share valuable knowledge through the network, it must have good network capabilities [33]. Hua Z. believed that cooperative attitude and participation motivation affects the stability of cooperative innovation. In turn, it will affect the evolutionary trend of innovation ecosystem [34]. Schwaiger found that enterprise competitiveness is not only driven by quality and performance, but also influenced by social responsibility [35].

At present, the trend of economic globalization has been further developed. And the competition among enterprises is increasingly fierce. The relationship between consumers and enterprises is no longer limited to the pure product or service. Corporate image has increasingly become one of the important ways to obtain and maintain competitive ad-vantages and interests [36]. Social responsibility not only affects the performance and development of the enterprise, but also affects the economic growth and long-term stability of whole society [37]. For example, in 2020, Meituan set up a "ComCare" of 200 million yuan to provide free special packages for medical workers. And it also provided 200,000 jobs for society [38]. It had greatly alleviated the huge impact of the epidemic on social employment. Social responsibility contributes to the enhancement of corporate value [39]. The social effect which comes from social responsibility practice, brings competitive advantage to the enterprises. There are three aspects: (1) The perform of social responsibility is conducive to the accumulation of institutional capital. It usually maintains a high degree of consistency with local or national policies. Hence, the enterprise will obtain corporate recognition and government support. It can contribute to the construction of a stable social and market environment for survival. (2) The perform of social responsibility is conducive to the accumulation of capital resources. It includes intellectual capital and social capital. Enterprises strengthen their connection with stakeholders through knowledge exchange with outside. In this way, they can enrich the network of social information resources. At the same time, it attracts more talents and acquires more knowledge accumulation. (3) The perform of social responsibility is conducive to the accumulation of brand capital. Good social responsibility will bring positive reputation to the enterprise. A positive image can endorse a business. In turn, the publicity effect encourages enterprises to pay more attention to their own image [40]. It will enable enterprises to take more social responsibilities voluntarily. That will cause a virtuous circle. At the same time, the differentiation of brand image can relieve some pressure of homogenization of market products [41]. As a result, enterprises can obtain sustainable competitive advantage through brand loyalty and brand extension [42]. However, the behavior decision of enterprise depends not only on the itself, but also on the change of the external environment. Government's subsidy for enterprises is as crucial as the regulation of the market. The government and society should to find a reasonable critical point to encourage enterprises to fulfill their social responsibilities voluntarily. Because the excessive social responsibility will lead to the increase of marginal cost of enterprises. Next, the subsequent diminishing returns will inhibit the innovation enthusiasm and reduce the core innovation ability. However, if the degree of social responsibility is too low, it will destroy the social and market order. Insufficient positive social influence hinders economic and social development [39]. To avoid speculation and rent-seeking, the government should give full play to its regulatory role. And to maximize the social effect, the government should strengthen supervision, relax policy support and encourage enterprises to fulfill their social responsibilities reasonably.

The most substantial effect of social effects is income. Corporate financial performance (CFP) index as the most intuitive main index has been recognized by the academic community. Considering the paradox of social responsibility and CFP, existing studies can be divided into two groups: On the one hand, some scholars believed that social responsibility damages financial performance due to its additional costs [43], [44]. On the other hand, social responsibility can help enterprises gain access to important re-sources. For example, positive enterprise image and excellent talent. Finally, the enterprise which fulfill social responsibility will improve its financial performance [45]–[47]. Halme verified that social responsibility has an impact on both financial performance and society through expand different concepts [48]. On this basis, Guo extended the traditional financial indicators. He believed that corporate competitiveness which is brought by social responsibility can promote the sustainability of success. However, the excessive fulfillment of social responsibility will also restrain the improvement of enterprise competitiveness [49]. Therefore, the proper implementation of social responsibility is particularly critical to the development of enterprises.

C. LITERATURE REVIEW AND RESEARCH FRAMEWORK

There are accumulation of the relationship between innovation enterprises and the discussion of social responsibility.

But these studies are based on different perspectives. At present, the research on the combination of R&D innovation system and social responsibility is not abundant. Especially, there are few researches on the optimal selection and influencing factors of inter-firm R&D innovation mode under social responsibility paradox perspective. Global epidemic brings more complex and diversified risks and challenges for innovation ecosystem. But at the same time, it will also bring more significant social effect. Based on it, this paper attempts to answer the questions as following: (1) Does social responsibility practice affect the choice of enterprise innovation paradigm? (2) Whether social responsibility will hinder the innovation ecosystem from realizing the goal of decentralized and symbiotic development? (3) Is there a R&D strategy that is compatible with responsibilities and benefits? (4) What are the effects of opportunism and free-riding behavior on returns?

The differential game theory originated in the military confrontation between the two sides in the 1950s. It's a combination of optimal control and game theory. Differential game is a new idea for solving coordinated control problems. R&D decision-making in an innovation ecosystem is a dynamic problem. In this system, time is continuous and each participant makes independent decisions. It meets the requirements of differential game theory.

Hence, this paper will be based on the perspective of social responsibility paradox. Then, we will construct innovative differential game equations under different situations. The aim of this paper is to abstract the R&D system of core technology innovation. On the basis of existing research, we will consider two types of innovation ecosystem: Master-slave innovation led by core enterprises and symbiotic innovation by decentralized. Then we compare the benefits of the two scenarios, which will help to select the optimal innovation model. Meanwhile, we will simulate the process and summarize influencing factors. We hope to provide a reference for enterprises in the innovation ecosystem when they adjust their R&D innovation strategies.

III. PROBLEM DESCRIPTION AND MODEL CONSTRUCTION

A. PROBLEM DESCRIPTION

This paper assumes that there are one core enterprise and one supporting enterprise in the initial innovation ecosystem. They are both independent and cooperative. On the one hand, the core enterprise carries out independent R&D. On the other hand, it cooperates with supporting enterprises through the innovation platform. Suppose the unit cost of developing a technology is fixed. In addition to the complementary resources docking with the core enterprises, supporting enterprises also upgrade their own core technologies. Both indigenous and imitative innovation can be profitable. The government provides technology subsidies and social responsibility incentives. As the hub of the system, the core enterprise has certain guiding power and resource advantages. Therefore, there are two forms of R&D decision making in collaborative innovation: (1) Core enterprise leads R&D. The relationship between the two enterprises is conform to the Stackelberg game model. (2) Core enterprises and supporting enterprises are in an equal position to conduct R&D. This conforms to the cooperative innovation model. Hence, we construct a Stackelberg master-subordinate game model and a collaborative innovation system model. Then compare them with the non-cooperative decentralized decision model.

B. MODEL CONSTURCTION

The parameter symbols and meanings involved in the model are shown in Table 1.

The cost of decision-making enterprise is described by quadratic function. The cost function of core enterprises and supporting enterprises in core technology and social responsibility at time t is expressed as:

$$C_{A_i}(t) = \mu_{A_i} A_i^2(t) \Big/ 2 \tag{1}$$

$$C_{B_i}(t) = \mu_{B_i} B_i^2(t) \Big/ 2$$
$$i = M, N \tag{2}$$

The technological level and social effect are dynamic changing processes. Enterprises can obtain new technologies through technology sharing. And it can also obtain more resources by taking advantage of additional benefits brought by social effect. Then the technological level and social effect will be improved. Therefore, by referring to the ideas in literature [50], the differential equation of collaborative research

TABLE 1. Parameter symbol and meaning.

Symbol	Meaning	Annotation
M	Core enterprise	
N	Supporting enterprise	
A_i	The amount of effort invested in core technology research and development of enterprise i	$i = M, N$
B_i	The degree of effort paid to fulfill social responsibility of enterprise i	$i = M, N$
μ_{Ai}	Core technology research and development effort cost coefficient of enterprise i	$i = M, N$
μ_{Bi}	Cost coefficient of effort to fulfill social responsibility of enterprise i	$i = M, N$
$U(t)$	The technological level of the innovation system at time t	Omit t for convenience
$E(t)$	The social effect brought about by the social responsibility of the innovation system at time t	Omit t for convenience
λ_1	The influence degree of core enterprise's R&D efforts on technology level	
λ_2	The influence degree of supporting enterprises' R&D efforts on the technical level	
γ_1	The degree to which the core enterprise fulfills social responsibility influences the social effect	
γ_2	The degree to which supporting enterprises fulfill their social responsibility affects the social effect	
δ	Technology knockout rate	$\delta > 0$
θ	The hindrance coefficient of excessive fulfillment of social responsibility to enterprise development	$\theta > 0$
π_0	Initial return	$\pi_0 \geq 0$
α	The influence factor of the enterprise's efforts in core technology research and development on the total revenue	
β	The influence factor of the enterprise's efforts in fulfilling social responsibility on the total revenue	
x	Proportion of earnings earned by core enterprises	
k_i	Government subsidy rate for core technology research and development of enterprise i	$i = M, N$
p_i	The reward rate of the government to fulfill its social responsibility for enterprise i	$i = M, N$
ω_i	High quality corporate reputation and social network relationships bring additional returns to the enterprise i	$i = M, N$
ρ	The discount rate at any time	

and development process can be obtained as follows:

$$U'(t) = dU(t)/dt = \lambda_1 A_M(t) + \lambda_2 A_N(t) - \delta U(t) \quad (3)$$

$$E'(t) = dE(t)/dt = \gamma_1 A_M(t) + \gamma_2 A_N(t) - \theta U(t) \quad (4)$$

When the decision-makers make their own optimal decisions independently, the respective objective functions of both parties are:

$$G_M = \max_{A_M \geq 0, B_M \geq 0} \int_0^\infty e^{-\rho t} \left[x\pi(t) - \mu_{A_M}(1-k_M) A_M^2 / 2 - \mu_{B_M}(1-p_M-\omega_M) B_M^2 / 2 \right] dt \quad (5)$$

$$G_N = \max_{A_N \geq 0, B_N \geq 0} \int_0^\infty e^{-\rho t} \left[(1-x)\pi(t) - \mu_{A_N}(1-k_N) A_N^2 / 2 - \mu_{B_N}(1-p_N-\omega_N) B_N^2 / 2 \right] dt$$

$$\pi(t) = \pi_0 + \alpha U(t) + \beta E(t) \quad (6)$$

Theorem 1: The optimal strategy in the case of independent decision-making is as follows:

$$\left(A_M^n, B_M^n\right) = \left(\frac{x\lambda_1\alpha}{\mu_{A_M}(1-k_M)(\rho+\delta)}, \frac{x\gamma_1\beta}{\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)} \right) \quad (7)$$

$$\left(A_N^n, B_N^n\right) = \left(\frac{(1-x)\lambda_2\alpha}{\mu_{A_N}(1-k_N)(\rho+\delta)}, \frac{(1-x)\gamma_2\beta}{\mu_{B_N}(1-p_N-\omega_N)(\rho+\theta)} \right) \quad (8)$$

Proof: It uses dynamic random control method to solve. The income function of enterprise i is $V_i(U,E)$. The function is continuously bounded and differentiable. For all $U \geq 0, E \geq 0$ satisfies the HJB equation. Then:

$$\begin{aligned} \rho V_M(U,E) = \max_{A_M \geq 0, B_M \geq 0} & [x(\pi_0 + \alpha U + \beta E) \\ & - (1-k_M)\mu_{A_M} A_M^2 / 2 \\ & - (1-p_M-\omega_M)\mu_{B_M} B_M^2 / 2 \\ & + (\partial V_M / \partial U)(\lambda_1 A_M + \lambda_2 A_N - \delta U) \\ & + (\partial V_M / \partial E)(\gamma_1 B_M + \gamma_2 B_N - \theta E)] \end{aligned} \quad (9)$$

$$\begin{aligned} \rho V_N(U,E) = \max_{A_N \geq 0, B_N \geq 0} & [(1-x)(\pi_0 + \alpha U + \beta E) \\ & - (1-k_N)\mu_{A_N} A_N^2 / 2 \\ & - \frac{1}{2}(1-p_N-\omega_N)\mu_{B_N} B_N^2 \\ & + (\partial V_N / \partial U)(\lambda_1 A_M + \lambda_2 A_N - \delta U) \\ & + (\partial V_N / \partial E)(\gamma_1 B_M + \gamma_2 B_N - \theta E)] \end{aligned} \quad (10)$$

Take the first partial derivatives with respect to (A_M, B_M) and (A_N, B_N) of the right side of (9) and (10) respectively. The optimal strategies of both parties can be obtained by solving:

$$(A_M, B_M) = \left(\frac{\lambda_1 (\partial V_M / \partial U)}{\mu_{A_M}(1-k_M)}, \frac{\gamma_1 (\partial V_M / \partial E)}{\mu_{B_M}(1-p_M-\omega_M)} \right) \quad (11)$$

$$(A_N, B_N) = \left(\frac{\lambda_2 (\partial V_N / \partial U)}{\mu_{A_N}(1-k_N)}, \frac{\gamma_2 (\partial V_N / \partial E)}{\mu_{B_N}(1-p_N-\omega_N)} \right) \quad (12)$$

By substituting (11) and (12) into (9) and (10), we can obtain:

$$\begin{aligned} \rho V_M(U,E) &= x\pi_0 + \left(x\alpha - \delta \frac{\partial V_M}{\partial U} \right) U + \left(x\beta - \theta \frac{\partial V_M}{\partial E} \right) E \\ & + \left(\lambda_1 \frac{\partial V_M}{\partial U} \right)^2 \Big/ 2\mu_{A_M}(1-k_M) \end{aligned}$$

$$
\begin{aligned}
&+\left(\gamma_1\frac{\partial V_M}{\partial E}\right)^2\Big/2\mu_{B_M}\left(1-p_M-\omega_M\right)\\
&+\lambda_2^2\left(\frac{\partial V_M}{\partial U}\right)\left(\frac{\partial V_N}{\partial U}\right)\Big/\mu_{A_N}\left(1-k_N\right)\\
&+\gamma_2^2\left(\frac{\partial V_M}{\partial E}\right)\left(\frac{\partial V_N}{\partial E}\right)\Big/\mu_{B_N}\left(1-p_N-\omega_N\right) \quad (13)
\end{aligned}
$$

$$
\begin{aligned}
&\rho V_N\left(U,E\right)\\
&=\left(1-x\right)\pi_0+\left[\left(1-x\right)\alpha-\delta\frac{\partial V_N}{\partial U}\right]U\\
&+\left[\left(1-x\right)\beta-\theta\frac{\partial V_N}{\partial E}\right]E\\
&+\left(\lambda_2\frac{\partial V_N}{\partial U}\right)^2\Big/2\mu_{A_N}\left(1-k_N\right)\\
&+\left(\gamma_2\frac{\partial V_N}{\partial E}\right)^2\Big/2\mu_{B_N}\left(1-p_N-\omega_N\right)\\
&+\lambda_1^2\left(\frac{\partial V_M}{\partial U}\right)\left(\frac{\partial V_N}{\partial U}\right)\Big/\mu_{A_M}\left(1-k_M\right)\\
&+\gamma_1^2\left(\frac{\partial V_M}{\partial E}\right)\left(\frac{\partial V_N}{\partial E}\right)\Big/\mu_{B_M}\left(1-p_M-\omega_M\right) \quad (14)
\end{aligned}
$$

Obtain the solutions of (13) and (14). It turns out to be a binary one degree function of U and E. Let:

$$
\begin{aligned}
V_M\left(U,E\right)&=a_1U+b_1E+c_1 \quad (15)\\
V_N\left(U,E\right)&=a_2U+b_2E+c_2 \quad (16)
\end{aligned}
$$

$a_1, a_2, b_1, b_2, c_1, c_2$ are constants. Then:

$$
\begin{aligned}
a_1&=x\alpha\big/\left(\rho+\delta\right)\\
a_2&=\left(1-x\right)\alpha\big/\left(\rho+\delta\right)\\
b_1&=x\beta\big/\left(\rho+\theta\right)\\
b_2&=\left(1-x\right)\beta\big/\left(\rho+\theta\right)\\
c_1&=x\pi_0\big/\rho+\left[x^2\lambda_1^2\Big/2\rho\mu_{A_M}\left(1-k_M\right)\left(\rho+\delta\right)^2\right.\\
&\quad\left.+x\left(1-x\right)\lambda_2^2\Big/\rho\mu_{A_N}\left(1-k_N\right)\left(\rho+\delta\right)^2\right]\alpha^2\\
&\quad+\left[x^2\gamma_1^2\Big/2\rho\mu_{B_M}\left(1-p_M-\omega_M\right)\left(\rho+\theta\right)^2\right.\\
&\quad\left.+x\left(1-x\right)\gamma_2^2\Big/\rho\mu_{B_N}\left(1-p_N-\omega_N\right)\left(\rho+\theta\right)^2\right]\beta^2\\
c_2&=\left(1-x\right)\pi_0\big/\rho\\
&\quad+\left[x\left(1-x\right)\lambda_1^2\Big/\rho\mu_{A_M}\left(1-k_M\right)\left(\rho+\delta\right)^2\right.\\
&\quad\left.+\left(1-x\right)^2\lambda_2^2\Big/2\rho\mu_{A_N}\left(1-k_N\right)\left(\rho+\delta\right)^2\right]\alpha^2\\
&\quad+\left[x\left(1-x\right)\gamma_1^2\Big/\rho\mu_{B_M}\left(1-p_M-\omega_M\right)\left(\rho+\theta\right)^2\right.\\
&\quad\left.+\left(1-x\right)^2\gamma_2^2\Big/2\rho\mu_{B_N}\left(1-p_N-\omega_N\right)\left(\rho+\theta\right)^2\right]\beta^2 \quad (17)
\end{aligned}
$$

Substitute the value of a_1, a_2, b_1, b_2 into (11) and (12) to obtain the optimal equilibrium strategy, will get (7) and (8). Substitute the optimal strategy (7) and (8) into (3) and (4). The optimal evolution trajectory of technological level and social effect can be obtained:

$$
\begin{aligned}
U^n&=H_1+\left(U_0-H_1\right)e^{-\delta t} \quad (18)\\
E^n&=H_2+\left(E_0-H_2\right)e^{-\theta t}\\
H_1&=\alpha x\lambda_1^2\Big/\delta\mu_{A_M}\left(1-k_M\right)\left(\rho+\delta\right)\\
&\quad+\alpha\left(1-x\right)\lambda_2^2\Big/\delta\mu_{A_N}\left(1-k_N\right)\left(\rho+\delta\right)\\
H_2&=\beta x\gamma_1^2\Big/\theta\mu_{B_M}\left(1-p_M-\omega_M\right)\left(\rho+\theta\right)\\
&\quad+\beta\left(1-x\right)\gamma_2^2\Big/\theta\mu_{B_N}\left(1-p_N-\omega_N\right)\left(\rho+\theta\right) \quad (19)
\end{aligned}
$$

Substitute each value in (17) into (15) and (16). The optimal income function of M and N is obtained. Thus, the optimal total profit value of the cooperative innovation R&D system under this circumstance can be obtained as follows:

$$
\begin{aligned}
V^n&=\left(\alpha\big/\rho+\delta\right)U^n+\left(\beta\big/\rho+\theta\right)E^n+\pi_0\big/\rho\\
&\quad+\left[\left(1-x^2\right)\lambda_2^2\Big/2\rho\mu_{A_N}\left(1-k_N\right)\left(\rho+\delta\right)^2\right.\\
&\quad\left.+x\left(2-x\right)\lambda_1^2\Big/2\rho\mu_{A_M}\left(1-k_M\right)\left(\rho+\delta\right)^2\right]\alpha^2\\
&\quad+\left[\left(1-x^2\right)\gamma_2^2\Big/2\rho\mu_{B_N}\left(1-p_N-\omega_N\right)\left(\rho+\theta\right)^2\right.\\
&\quad\left.+x\left(2-x\right)\gamma_1^2\Big/2\rho\mu_{B_M}\left(1-p_M-\omega_M\right)\left(\rho+\theta\right)^2\right]\beta^2 \quad (20)
\end{aligned}
$$

IV. STACKELBERG GAME MODEL

In this case, the core enterprise M encourages the supporting enterprise N to cooperate in innovation. M will bear a certain proportion of the cost of technology research and development and social responsibility fulfillment. Use q_A and q_B to denote the share. M determines its optimal strategy firstly as (A_M, B_M). Enterprise N observes the decision of M then makes its own optimal strategy as (A_N, B_N).

At this point, the objective function of each enterprise is:

$$
\begin{aligned}
G_M=&\max_{A_M\ge0,B_M\ge0}\int_0^\infty e^{-\rho t}\left[x\pi\left(t\right)-\mu_{A_M}\left(1-k_M\right)A_M^2\Big/2\right.\\
&-\mu_{B_M}\left(1-p_M-\omega_M\right)B_M^2\Big/2-\mu_{A_N}q_A\left(1-k_N\right)A_N^2\Big/2\\
&\left.-\mu_{B_N}q_B\left(1-p_N-\omega_N\right)B_N^2\Big/2\right]dt \quad (21)
\end{aligned}
$$

$$
\begin{aligned}
G_N=&\max_{A_N\ge0,B_N\ge0}\int_0^\infty e^{-\rho t}\\
&\times\left[\left(1-x\right)\pi\left(t\right)-\mu_{A_N}\left(1-k_N-q_A\right)A_N^2\Big/2\right.\\
&\left.-\mu_{B_N}\left(1-p_N-\omega_N-q_B\right)B_N^2\Big/2\right]dt \quad (22)
\end{aligned}
$$

Theorem 2: In Stackelberg Game model, the optimal strategies of both enterprises are as follows:

$$
\left(A_M^s,B_M^s\right)=\left(\frac{x\lambda_1\alpha}{\mu_{A_M}\left(1-k_M\right)\left(\rho+\delta\right)},\frac{x\gamma_1\beta}{\mu_{B_M}\left(1-p_M-\omega_M\right)\left(\rho+\theta\right)}\right) \quad (23)
$$

$$\left(A_N^s, B_N^s\right) = \left(\frac{\lambda_2\alpha\left[2x+(1-x)(1-k_N)\right]}{2\mu_{A_N}(1-k_N)^2(\rho+\delta)}\right.$$
$$\left.\frac{\gamma_2\beta\left[2x+(1-x)(1-p_N-\omega_N)\right]}{2\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)}\right) \tag{24}$$

$$\begin{aligned} q_A^s &= 2x(1-k_N)-(1-x)(1-k_N)^2/2x \\ &\quad +(1-x)(1-k_N), \\ &\quad 1-k_N/3-k_N < x < 1 \end{aligned} \tag{25}$$

$$\begin{aligned} q_B^s &= 2x(1-p_N-\omega_N)/2x+(1-x)(1-p_N-\omega_N), \\ &\quad -(1-x)(1-p_N-\omega_N)^2/2x+(1-x) \\ &\quad \times(1-p_N-\omega_N) \\ &\quad 1-p_N-\omega_N/3-p_N-\omega_N < x < 1 \end{aligned} \tag{26}$$

When $0 < x \le 1-k_N/3-k_N, q_A^s = 0$,
when $0 < x \le 1-p_N-\omega_N/3-p_N-\omega_N, q_B^s = 0$

Proof: Adopt the backward induction method to solve. As a rational decision maker, the supporting enterprise can predict the optimal strategy choice of the core enterprise accurately. Then the enterprise can choose its own strategy according to the given strategy of the core enterprise which is (A_M, B_M, q_A, q_B). The income function of enterprise i is V_i (U, E). The function is continuously bounded and differentiable. For all $U \ge 0$, $E \ge 0$ satisfies the HJB equation. Then:

$$\begin{aligned} &\rho V_M(U,E) \\ &= \max_{A_M\ge0,B_M\ge0}\Big[x(\pi_0+\alpha U+\beta E)-(1-k_M)\mu_{A_M}A_M^2/2 \\ &\quad -(1-p_M-\omega_M)\mu_{B_M}B_M^2/2 \\ &\quad -\mu_{A_N}q_A(1-k_N)A_N^2/2-\mu_{B_N}q_B(1-p_N-\omega_N)B_N^2/2 \\ &\quad +\left(\partial V_M/\partial U\right)(\lambda_1A_M+\lambda_2A_N-\delta U) \\ &\quad +\left(\partial V_M/\partial E\right)(\gamma_1B_M+\gamma_2B_N-\theta E)\Big] \end{aligned} \tag{27}$$

$$\begin{aligned} &\rho V_N(U,E) \\ &= \max_{A_N\ge0,B_N\ge0}\big[(1-x)(\pi_0+\alpha U+\beta E) \\ &\quad -(1-k_N-q_A)\mu_{A_N}A_N^2/2 \\ &\quad -(1-p_N-\omega_N-q_B)\mu_{B_N}B_N^2/2 \\ &\quad +\left(\partial V_N/\partial U\right)(\lambda_1A_M+\lambda_2A_N-\delta U) \\ &\quad +\left(\partial V_N/\partial E\right)(\gamma_1B_M+\gamma_2B_N-\theta E)\big] \end{aligned} \tag{28}$$

Equations (23) and (24) are concave functions. The optimal strategy can be obtained from the first-order condition as follows (29)–(32), as shown at the bottom of the page.

Substituting (25), (26) and (27) into (23) and (24), (33) and (34), as shown at the bottom of the next page.

By observing the form of (28) and (29), it can be inferred that its solution is a binary one-order function of the sum. Let:

$$V_M(U,E) = a_3U+b_3E+c_3 \tag{35}$$
$$V_N(U,E) = a_4U+b_4E+c_4 \tag{36}$$

a_3, a_4, b_3, b_4, c_3, c_4 are constants. Substituting V_M (U, E), V_N (U, E) and the first-order partial derivatives into (28) and (29), and simplifying and sorting can be obtained as follows (37), as shown at the bottom of the next page Substitute the value of a_3, a_4, b_3, b_4 into (29)-(32). The optimal strategy of the two enterprises and the optimal cost-sharing ratio can be obtained by calculation.

Then, the results are substituted into (3) and (4) and solved to obtain the optimal evolution trajectory of technological level and social effect:

$$U^s = H_3+(U_0-H_3)e^{-\delta t} \tag{38}$$

$$\begin{aligned} E^s &= H_4+(E_0-H_4)e^{-\theta t} \\ H_3 &= \alpha x\lambda_1^2/\delta\mu_{A_M}(1-k_M)(\rho+\delta) \\ &\quad +\alpha\lambda_2^2[2x+(1-x)(1-k_N)]/2\delta\mu_{A_N}(1-k_N)^2(\rho+\delta) \\ H_4 &= \beta x\gamma_1^2/\theta\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta) \\ &\quad +\beta\gamma_2^2[2x+(1-x)(1-p_N-\omega_N)]/ \\ &\quad 2\theta\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta) \end{aligned} \tag{39}$$

Substitute each value in (37) into (35) and (36). The optimal income function of enterprise M and enterprise N is obtained. Thus, the optimal total profit value of the cooperative innovation R&D system under this circumstance can be

$$\left(A_M, B_M\right) = \left(\frac{\lambda_1\left(\partial V_M/\partial U\right)}{\mu_{A_M}(1-k_M)}, \frac{\gamma_1\left(\partial V_M/\partial E\right)}{\mu_{B_M}(1-p_M-\omega_M)}\right) \tag{29}$$

$$\left(A_N, B_N\right) = \left(\frac{\lambda_2\left(\partial V_N/\partial U\right)}{\mu_{A_N}(1-k_N-q_A)}, \frac{\gamma_2\left(\partial V_N/\partial E\right)}{\mu_{B_N}(1-p_N-\omega_N-q_B)}\right) \tag{30}$$

$$q_A = \frac{2(1-k_N)\left(\partial V_M/\partial U\right)-(1-k_N)^2\left(\partial V_N/\partial U\right)}{2\left(\partial V_M/\partial U\right)+(1-k_N)\left(\partial V_N/\partial U\right)} \tag{31}$$

$$q_B = \frac{2(1-p_N-\omega_N)\left(\partial V_M/\partial E\right)-(1-p_N-\omega_N)^2\left(\partial V_N/\partial E\right)}{2\left(\partial V_M/\partial E\right)+(1-p_N-\omega_N)\left(\partial V_N/\partial E\right)} \tag{32}$$

obtained as follows (40), as shown at the bottom of the next page.

V. CO-SYMBIOSIS RESEARCH AND DEVELOPMENT GAME

The total revenue of the co-symbiosis system is:

$$\prod = G_M + G_N$$

$$= \max_{A_i \geq 0, B_i \geq 0} \int_0^{\infty} e^{-\rho t} \Big[\pi(t) - \mu_{A_M}(1-k_M) A_M^2 \big/ 2 - \mu_{B_M}(1-p_M-\omega_M) B_M^2 \big/ 2 - \mu_{A_N}(1-k_N) A_N^2 \big/ 2 - \mu_{B_N}(1-p_N-\omega_N) B_N^2 \big/ 2 \Big] dt$$

$$i = M, N \tag{41}$$

$$\begin{aligned}
\rho V_M(U,E) = {} & x(\pi_0 + \alpha U + \beta E) + \frac{\lambda_1^2 \left(\frac{\partial V_M}{\partial U}\right)^2}{2\mu_{A_M}(1-k_M)} + \frac{\gamma_1^2 \left(\frac{\partial V_M}{\partial E}\right)^2}{2\mu_{B_M}(1-p_M-\omega_M)} \\
& - \frac{\lambda_2^2 \left[2(1-k_N)\frac{\partial V_M}{\partial U} - (1-k_N)^2 \left(\frac{\partial V_N}{\partial U}\right)\right]\left[2\frac{\partial V_M}{\partial U} + (1-k_N)\left(\frac{\partial V_N}{\partial U}\right)\right]}{8\mu_{A_N}(1-k_N)^3} \\
& - \frac{\gamma_2^2 \left[2(1-p_N-\omega_N)\frac{\partial V_M}{\partial E} - (1-p_N-\omega_N)^2 \left(\frac{\partial V_N}{\partial E}\right)\right]\left[2\frac{\partial V_M}{\partial E} + (1-p_N-\omega_N)\left(\frac{\partial V_N}{\partial E}\right)\right]}{8\mu_{B_N}(1-p_N-\omega_N)^3} \\
& + \frac{\lambda_2^2 \frac{\partial V_M}{\partial U}\left[2\frac{\partial V_M}{\partial U} + (1-k_N)\left(\frac{\partial V_N}{\partial U}\right)\right]}{2\mu_{A_N}(1-k_N)^2} + \frac{\gamma_2^2 \frac{\partial V_M}{\partial E}\left[2\frac{\partial V_M}{\partial E} + (1-p_N-\omega_N)\left(\frac{\partial V_N}{\partial E}\right)\right]}{2\mu_{B_N}(1-p_N-\omega_N)^2} \\
& - \delta U \frac{\partial V_M}{\partial U} - \theta E \frac{\partial V_M}{\partial E}
\end{aligned} \tag{33}$$

$$\begin{aligned}
\rho V_N(U,E) = {} & (1-x)(\pi_0 + \alpha U + \beta E) \\
& + \frac{\lambda_2^2 (\partial V_N / \partial U)\left[2(\partial V_M/\partial U) + (1-k_N)(\partial V_N/\partial U)\right]}{4\mu_{A_N}(1-k_N)^2} \\
& + \frac{\gamma_2^2 (\partial V_N / \partial E)\left[2(\partial V_M/\partial E) + (1-p_N-\omega_N)(\partial V_N/\partial E)\right]}{4\mu_{B_N}(1-p_N-\omega_N)^2} \\
& + \frac{\lambda_1^2 (\partial V_M/\partial U)(\partial V_N/\partial U)}{\mu_{A_M}(1-k_M)} + \frac{\gamma_1^2 (\partial V_M/\partial E)(\partial V_N/\partial E)}{\mu_{B_M}(1-p_M-\omega_M)} \\
& - \delta U (\partial V_N/\partial U) - \theta E (\partial V_N/\partial E)
\end{aligned} \tag{34}$$

$$\begin{aligned}
a_3 &= x\alpha \big/ (\rho+\delta) \\
a_4 &= (1-x)\alpha \big/ (\rho+\delta) \\
b_3 &= x\beta \big/ (\rho+\theta) \\
b_4 &= (1-x)\beta \big/ (\rho+\theta) \\
c_3 &= x\pi_0 \big/ \rho + \Big\{ x^2\lambda_1^2 \big/ 2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2 \\
&\quad + \frac{\lambda_2^2\left[4x^2 + 4x(1-x)(1-k_N) + (1-x)^2(1-k_N)^2\right]}{8\rho\mu_{A_N}(1-k_N)^2(\rho+\delta)^2} \Big\} \alpha^2 \\
&\quad + \Big\{ x^2\gamma_1^2 \big/ 2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2 \\
&\quad + \frac{\gamma_2^2\left[4x^2 + 4x(1-x)(1-p_N-\omega_N) + (1-x)^2(1-p_N-\omega_N)^2\right]}{8\rho\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)^2} \Big\} \beta^2 \\
c_4 &= (1-x)\pi_0 \big/ \rho + \Big[x(1-x)\lambda_1^2 \big/ \rho\mu_{A_M}(1-k_M)(\rho+\delta)^2 \\
&\quad + (1-x)^2\lambda_2^2 \big/ 4\rho\mu_{A_N}(1-k_N)^2(\rho+\delta)^2 \Big] \alpha^2 \\
&\quad + \Big[x(1-x)\gamma_1^2 \big/ \rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2 \\
&\quad + (1-x)^2\gamma_2^2 \big/ 4\rho\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)^2 \Big] \beta^2
\end{aligned} \tag{37}$$

Theorem 3: In the co-symbiosis R&D Game between core enterprise and supporting enterprise, the optimal strategies as follows:

$$\left(A_M^c, B_M^c\right) = \left(\frac{\lambda_1\alpha}{\mu_{A_M}(1-k_M)(\rho+\delta)}, \frac{\gamma_1\beta}{\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)}\right) \quad (42)$$

$$\left(A_N^c, B_N^c\right) = \left(\frac{\lambda_2\alpha}{\mu_{A_N}(1-k_N)(\rho+\delta)}, \frac{\gamma_2\beta}{\mu_{B_N}(1-p_N-\omega_N)(\rho+\theta)}\right) \quad (43)$$

Proof: It is using dynamic random control method to solve. The income function of enterprise i is $V_i\ (U,E)$. The function is continuously bounded and differentiable. For all $U \geq 0$, $E \geq 0$ satisfies the HJB equation. Then:

$$\begin{aligned}\rho V(U,E) &= \max_{A_i\geq 0, B_i\geq 0}\Big[(\pi_0+\alpha U+\beta E)-(1-k_M)\mu_{A_M}A_M^2/2 \\ &\quad -(1-p_M-\omega_M)\mu_{B_M}B_M^2/2-\mu_{A_N}(1-k_N)A_N^2/2 \\ &\quad -\mu_{B_N}(1-p_N-\omega_N)B_N^2/2 \\ &\quad +\frac{\partial V}{\partial U}(\lambda_1A_M+\lambda_2A_N-\delta U)+\frac{\partial V}{\partial E}(\gamma_1B_M+\gamma_2B_N-\theta E)\Big]\end{aligned}$$

$$i = M, N \quad (44)$$

Equation (44) is the concave function of (A_M, B_M) and (A_N, B_N). According to the first-order condition, the optimal strategies can be obtained as follows:

$$(A_M, B_M) = \left(\frac{\lambda_1(\partial V/\partial U)}{(1-k_M)\mu_{A_M}}, \frac{\gamma_1(\partial V/\partial E)}{(1-p_M-\omega_M)\mu_{B_M}}\right) \quad (45)$$

$$(A_N, B_N) = \left(\frac{\lambda_2(\partial V/\partial U)}{(1-k_N)\mu_{A_N}}, \frac{\gamma_2(\partial V/\partial E)}{(1-p_N-\omega_N)\mu_{B_N}}\right) \quad (46)$$

Substitute (45) and (46) into (44) to simplify and summarize as follows:

$$\begin{aligned}\rho V(U,E) &= \pi_0+\left[\alpha-\delta(\partial V/\partial U)\right]U+\left[\beta-\theta(\partial V/\partial E)\right]E \\ &\quad +\frac{\lambda_1^2(\partial V/\partial U)^2}{2(1-k_M)\mu_{A_M}}+\frac{\gamma_1^2(\partial V/\partial E)^2}{2(1-p_M-\omega_M)\mu_{B_M}} \\ &\quad +\frac{\lambda_2^2(\partial V/\partial U)^2}{2(1-k_N)\mu_{A_N}}+\frac{\gamma_2^2(\partial V/\partial E)^2}{2(1-p_N-\omega_N)\mu_{B_N}}\end{aligned} \quad (47)$$

Observe the form of (47). It surmised that the solution was a binary one function of U and E. Let:

$$V(U,E) = aU + bE + c \quad (48)$$

a, b, c are constants. It can be obtained by collating:

$$\begin{aligned}a &= \alpha/(\rho+\delta) \\ b &= \beta/(\rho+\theta) \\ c &= \pi_0/\rho+\Big[\lambda_1^2/2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2 \\ &\quad +\lambda_2^2/2\rho\mu_{A_N}(1-k_N)(\rho+\delta)^2\Big]\alpha^2 \\ &\quad +\Big[\gamma_1^2/2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2 \\ &\quad +\gamma_2^2/2\rho\mu_{B_N}(1-p_N-\omega_N)(\rho+\theta)^2\Big]\beta^2\end{aligned} \quad (49)$$

By substituting the value of a, b, c into (45) and (46), the optimal equilibrium strategy can be obtained. Which is (42) and (43). Substitute the optimal strategy into (3) and (4). The optimal evolution trajectory of technological level and social effect can be solved as follows:

$$\begin{aligned}U^c &= H_5+(U_0-H_5)e^{-\delta t} \\ E^c &= H_6+(E_0-H_6)e^{-\theta t}\end{aligned} \quad (50)$$

$$\begin{aligned}H_5 &= \alpha\lambda_1^2/\delta\mu_{A_M}(1-k_M)(\rho+\delta) \\ &\quad +\alpha\lambda_2^2/\delta\mu_{A_N}(1-k_N)(\rho+\delta) \\ H_6 &= \beta\gamma_1^2/\theta\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta) \\ &\quad +\beta\gamma_2^2/\theta\mu_{B_N}(1-p_N-\omega_N)(\rho+\theta)\end{aligned} \quad (51)$$

Substitute each value in (49) into (48). The optimal revenue function of the enterprise alliance is obtained. Thus, the optimal total profit value of the cooperative innovation R&D system under this circumstance can be obtained as follows:

$$V^c = \frac{\alpha}{\rho+\delta}U^c+\frac{\beta}{\rho+\theta}E^c+\frac{\pi_0}{\rho}$$

$$\begin{aligned}V^s &= \frac{\alpha}{\rho+\delta}U^s+\frac{\beta}{\rho+\theta}E^s+\frac{\pi_0}{\rho} \\ &\quad +\frac{x(2-x)\lambda_1^2\alpha^2}{2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2}+\frac{x(2-x)\gamma_1^2\beta^2}{2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2} \\ &\quad +\frac{\left[4x^2+4x(1-x)(1-k_N)+(1-x)^2(1-k_N)^2+2(1-x)^2\right]\lambda_2^2\alpha^2}{8\rho\mu_{A_N}(1-k_N)^2(\rho+\delta)^2} \\ &\quad +\frac{\left[4x^2+4x(1-x)(1-p_N-\omega_N)+(1-x)^2(1-p_N-\omega_N)^2+2(1-x)^2\right]\lambda_2^2\beta^2}{8\rho\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)^2}\end{aligned} \quad (40)$$

$$+\left[\frac{\lambda_1^2}{2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2}+\frac{\lambda_2^2}{2\rho\mu_{A_N}(1-k_N)(\rho+\delta)^2}\right]\alpha^2+\left[\frac{\gamma_1^2}{2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2}+\frac{\gamma_2^2}{2\rho\mu_{B_N}(1-p_N-\omega_N)(\rho+\theta)^2}\right]\beta^2 \quad (52)$$

VI. COMPARATIVE ANALYSIS

Proposition 1:

$$A_M^c > A_M^s = A_M^n$$
$$B_M^c > B_M^s = B_M^n$$

Proof:

$$\begin{aligned}A_M^c - A_M^s &= \lambda_1\alpha/\mu_{A_M}(1-k_M)(\rho+\delta) - x\lambda_1\alpha/\mu_{A_M}(1-k_M)(\rho+\delta)\\ &= (1-x)\lambda_1\alpha/\mu_{A_M}(1-k_M)(\rho+\delta) > 0 \quad (53)\end{aligned}$$

$$\begin{aligned}B_M^c - B_M^s &= \gamma_1\beta/\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta) - x\gamma_1\beta/\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)\\ &= (1-x)\gamma_1\beta/\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta) > 0 \quad (54)\end{aligned}$$

Proposition 2: The core enterprise is the leader in system. When it gains the income proportion in the interval of (1/3, 1). M shares part of the cost for supporting enterprise N. And N gets an incentive from that. So the effort level of N is higher than that of the Nash game. When M gains the income proportion in the interval of $(0, 1/3]$ The effort level of N does not change. In this case, the first and second social responsibility paradoxes emerge. Core enterprises can take the initiative to undertake social responsibilities. But there is a boundary. When the proportion of earnings is lower than one third, it should not share the cost for supporting enterprise. If the core enterprise pursuit social effects blindly, its self-interest will be hurt. At the same time, it will encourage the opportunism mentality of supporting enterprise. Finally it will form the parasitic and dependent cooperative relations.

When $x \in (1/3, 1)$:

$$A_N^s - A_N^n = \frac{[x(3-K_N)+K_N-1]\lambda_2\alpha}{2\mu_{A_N}(1-K_N)^2(\rho+\delta)} > \frac{[1-K_N+K_N-1]\lambda_2\alpha}{2\mu_{A_N}(1-K_N)^2(\rho+\delta)} = 0 \quad (55)$$

Therefore

$$A_N^s - A_N^n > 0, B_N^s - B_N^n > 0.$$

The proof procedure is slight.

Corollary 1: The core enterprise makes the same effort in the non-cooperative decentralized game as in the master-slave game. And on the basis of ensuring its own income, the core enterprise will provides cost sharing and other supportive activities to supporting enterprise.

Proposition 3: When the subsidy rate of government to N is (0, 2/3). The enterprise will think about collaboration. When it is more than 2/3, the paradox of social responsibility causes the contradiction to highlight. In other words, Excessive government incentives will lead to the imbalance of the innovation ecosystem. Enterprise will only choose non-cooperative and master-slave game situation.

Hence, if the innovation ecosystem wants to realize the ideal of symbiosis, $K_N \in (0, 2/3)$.

Contrast the co-symbiosis research with Stackelberg, x is related to K_N.

When $x > (1-K_N)/(1+K_N)$, $A_N^s > A_N^c$, $U^c > U^s$, $E^c > E^s$.

$(1-K_N)/(1+K_N)$ is a concave function of K_N.

When $0 < x < (1-K_N)/(1+K_N)$, $A_N^c > A_N^s$, $U^c > U^s$, $E^c > E^s$.

Combined with proposition 2. In the cooperative symbiotic game case, the ratio of core enterprise earnings is $1/3 < x < (1-K_N)/(1+K_N)$. At this time, the profit ratio of the M is affected by the subsidy rate of the government for N. The promotion of subsidy rate promotes the enthusiasm of supporting enterprises. While improving their own earnings, it also brings additional earnings for the core enterprise. Therefore, the enterprises of both sides gain more profits. But the share of earnings of core enterprises decreased.

Corollary 2: Within a certain range, the higher the government subsidies for R&D and social responsibility of supporting enterprises, the higher the proportion of supporting enterprises' earnings.

Proposition 4:

$$U^c > U^s > U^n$$
$$E^c > E^s > E^n$$

Proof:

We can draw the following conclusions through the foregoing:

$$\frac{dU}{dH} = 1 - e^{-\delta t} > 0\,(\delta > 0)$$

Hence, U is an increment of H.

In a similar way, we can get:

$$\frac{dE}{dH} = 1 - e^{-\theta t} > 0\,(\theta > 0)$$

In summary:

$$U^c > U^s > U^n$$
$$E^c > E^s > E^n$$

Corollary 3: Core enterprises and supporting enterprises invest the most in technology R&D and social responsibility under the condition of coordinate symbiosis. Moreover, the overall technical level and social effect are higher than the case of master-slave R&D and non-cooperative R&D.

Proposition 5:

$$V^c > V^s > V^n$$
$$V_M^s > V_M^n, V_N^s > V_N^n$$

Proof:

$$V_M^s - V_M^n = \frac{\lambda_2^2\alpha^2\left[2x-(1-x)(1-k_N)\right]^2}{8\rho\mu_{A_N}(1-k_N)^2(\rho+\delta)^2} + \frac{\gamma_2^2\beta^2\left[2x-(1-x)(1-p_N-\omega_N)\right]^2}{8\rho\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)^2} > 0 \quad (56)$$

$$V_N^s - V_N^n = \frac{(1-x)^2\lambda_2^2\alpha^2}{4\rho\mu_{A_N}(1-k_N)^2(\rho+\delta)^2} + \frac{(1-x)^2\gamma_2^2\beta^2}{4\rho\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)^2} > 0 \quad (57)$$

It can be known from proposition 3.

When 1/3$< x <$ (1- K_N)/(1+K_N), $U^c > U^s, E^c > E^s$.

Therefore (58), as shown at the bottom of the next page.

Corollary 4: When the core enterprise and supporting enterprise adopt the master-slave R&D, the income is higher than independent case. The overall revenue of coordinate symbiosis is higher than that of master-slave and non-cooperative.

VII. ANALYSIS OF CALCULATION EXAMPLES

The parameter values of literature [50] and literature [51] were used for reference. Combined with the above analysis of the parameters of the conditions. Relevant parameters such as strategy, income, technical level and social effect of the three R&D scenarios under social responsibility are assigned as follows:

$\mu_{A_M} = 0.4, \mu_{A_N} = 0.3, \mu_{B_M} = 0.3, \mu_{B_N} = 0.2, \lambda_1 = 0.4, \lambda_2 = 0.2, \gamma_1 = 0.3, \gamma_2 = 0.2, \delta = 0.2, \theta = 0.1, \alpha = 3, \beta = 2, x = 0.6, k_M = 0.2, k_N = 0.2, p_M = 0.3, p_N = 0.3, \omega_M = 0.2, \omega_N = 0.2, \rho = 0.1, \pi_0 = 20, t = 1.$

The following results can be obtained by bringing the values into each formula:

$A_M^n = 7.5, A_M^s = 7.5, A_M^c = 12.5, B_M^n = 12, B_M^s = 12, B_M^c = 20, A_N^n = 3.33, A_N^s = 7.92, A_N^c = 8.33, U^n = 11.5, E^n = 23.2, U^s = 12.33, E^s = 27.2, U^c = 14.2, E^c = 28, V_M^n = 662.16, V_N^n = 528.09, V_M^s = 658.74, V_N^s = 542.46, V^n = 1190.25, V^s = 1201.2, V^c = 1230.36.$

Above all, propositions 1-5 are proved.

In order to further verify the conclusion. According to the special solution function expression of the first-order differential equation, we can get:

$$U^n = 18.33 - 8.33e^{-0.2t}, E^n = 20 - 32e^{-0.1t}$$
$$V_M^n = 6U + 6E + 453.96, V_N^n = 4U + 4E + 389.29$$
$$V^n = 10U + 10E + 843.25$$
$$U^s = 22.92 - 12.92e^{-0.2t}, E^s = 92 - 72e^{-0.1t}$$
$$V_M^s = 6U + 6E + 421.56, V_N^s = 4U + 4E + 384.34$$

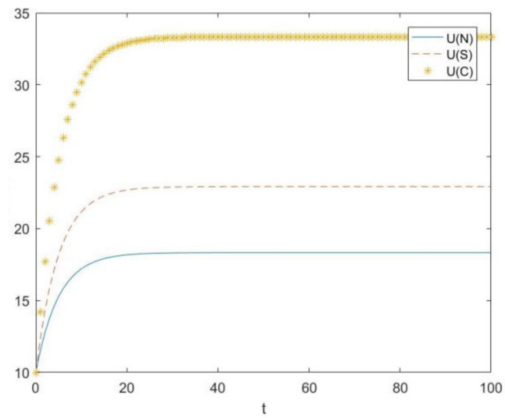

FIGURE 1. Comparison of technological level trends of R&D systems of enterprises of both sides under the three situations.

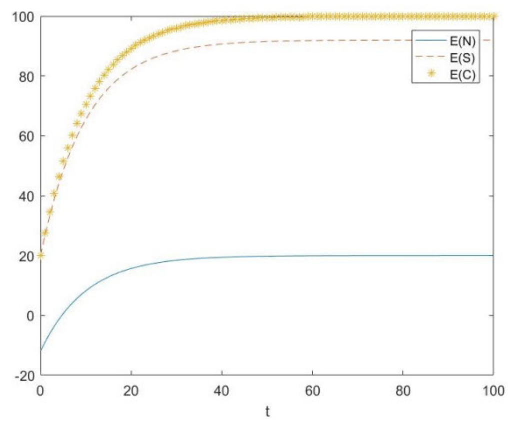

FIGURE 2. Comparison of social effect trends of Research and Development systems of the two sides under the three situations.

$$V^s = 10U + 10E + 805.9$$
$$U^c = 33.33 - 23.33e^{-0.2t}, E^c = 100 - 80e^{-0.1t}$$
$$V^c = 10U + 10E + 808.36$$

The simulation results are shown in Fig. 1-10.

A. COMPARISON OF TRENDS IN THREE CASES

The technological levels and social effect trends of the R&D systems of both companies in the three situations are shown in the following figures:

From Fig. 1 and Fig. 2, the technological level and social effect of the R&D system constituted by the core enterprises and supporting enterprises are positively correlated with time. They always maintain the highest level of collaboration. The second is the master-slave situation. Both are higher than non-cooperative independent research and development. The early change range is large, and then basically tends to be stable. The conclusion drawn by proposition 4 is verified.

B. REVENUE INFLUENCING FACTORS

The impact of R&D patterns, government incentives on revenues, and overall revenues are shown in the following figures:

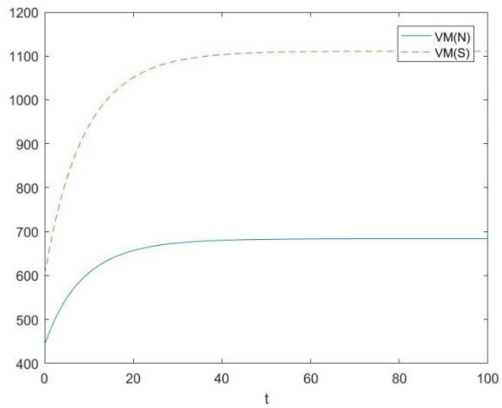

FIGURE 3. Comparison of earnings of core enterprises under master-slave Research and Development and non-cooperative Research and Development.

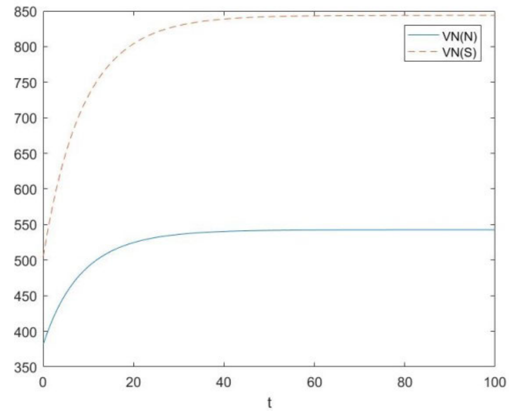

FIGURE 4. Comparison of earnings of supporting enterprises under master-slave Research and Development and non-cooperative Research and Development.

It can be seen from Fig. 3-6, In the case of master-slave R&D, both the core enterprise and the supporting enterprise have higher profits than the case of non-cooperative independent R&D. This demonstrates the positive effect of the innovation ecosystem on corporate earnings. In terms of overall system benefits, the collaborative situation is higher than the master-slave situation. And with the increase of government incentives to supporting enterprises, the system income increases. But from the proportion of the point of view, the core enterprise income proportion decreases. This validates the conclusion drawn by propositions 3 and 5, and indirectly validates propositions 2.

$$
\begin{aligned}
V^c - V^s &= \frac{\alpha}{\rho+\delta}\left(U^c - U^s\right) + \frac{\beta}{\rho+\theta}\left(E^c - E^s\right) \\
&\quad + \frac{\lambda_1^2\alpha^2}{2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2} - \frac{x(2-x)\lambda_1^2\alpha^2}{2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2} \\
&\quad + \frac{\lambda_2^2\alpha^2}{2\rho\mu_{A_N}(1-k_N)(\rho+\delta)^2} \\
&\quad - \frac{\left[4x^2+4x(1-x)(1-k_N)+(1-x)^2(1-k_N)^2+2(1-x)^2\right]\lambda_2^2\alpha^2}{8\rho\mu_{A_N}(1-k_N)^2(\rho+\delta)^2} \\
&\quad + \frac{\gamma_1^2\beta^2}{2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2} - \frac{x(2-x)\gamma_1^2\beta^2}{2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2} \\
&\quad + \frac{\gamma_2^2\beta^2}{2\rho\mu_{B_N}(1-p_N-\omega_N)(\rho+\theta)^2} \\
&\quad - \frac{\left[4x^2+4x(1-x)(1-p_N-\omega_N)+(1-x)^2(1-p_N-\omega_N)^2+2(1-x)^2\right]\lambda_2^2\beta^2}{8\rho\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)^2} \\
&> \frac{\alpha}{\rho+\delta}\left(U^c - U^s\right) + \frac{\beta}{\rho+\theta}\left(E^c - E^s\right) \\
&\quad + \frac{\lambda_1^2\alpha^2}{2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2} - \frac{x(2-x)\lambda_1^2\alpha^2}{2\rho\mu_{A_M}(1-k_M)(\rho+\delta)^2} \\
&\quad + \frac{\lambda_2^2\alpha^2}{2\rho\mu_{A_N}(1-k_N)(\rho+\delta)^2} - \frac{11x^2\lambda_2^2\alpha^2}{8\rho\mu_{A_N}(1-k_N)^2(\rho+\delta)^2} \\
&\quad + \frac{\gamma_1^2\beta^2}{2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2} - \frac{x(2-x)\gamma_1^2\beta^2}{2\rho\mu_{B_M}(1-p_M-\omega_M)(\rho+\theta)^2} \\
&\quad + \frac{\gamma_2^2\beta^2}{2\rho\mu_{B_N}(1-p_N-\omega_N)(\rho+\theta)^2} - \frac{11x^2\lambda_2^2\beta^2}{8\rho\mu_{B_N}(1-p_N-\omega_N)^2(\rho+\theta)^2} \\
&> 0
\end{aligned} \tag{58}
$$

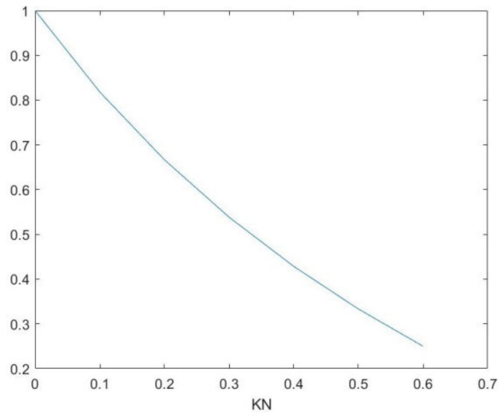

FIGURE 5. Influence of government incentives to supporting enterprises on the proportion of revenue of core enterprise.

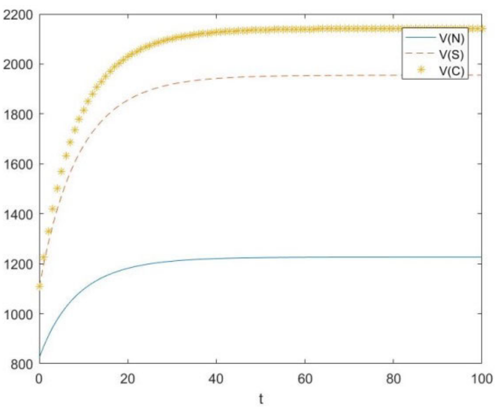

FIGURE 6. Comparison of the overall benefits of the Research and Development system under the three situations.

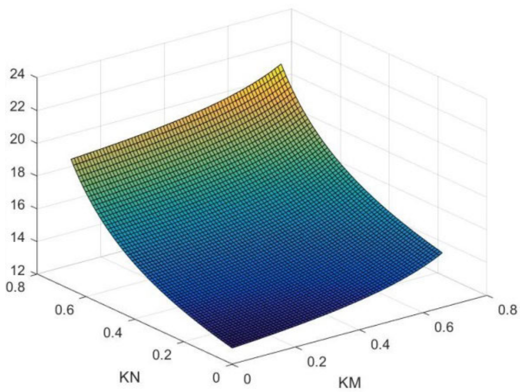

FIGURE 7. Influence of government subsidies for Research and Development on the technical level of the co-symbiosis system.

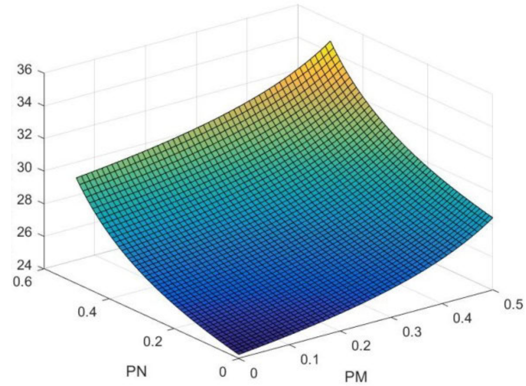

FIGURE 8. Influence of government incentives for social responsibility on the social effect of the co-symbiosis system.

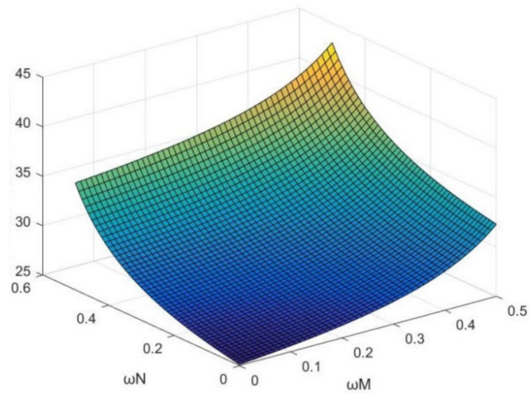

FIGURE 9. Influence of corporate reputation and social relations on the social effect of the co-symbiosis system.

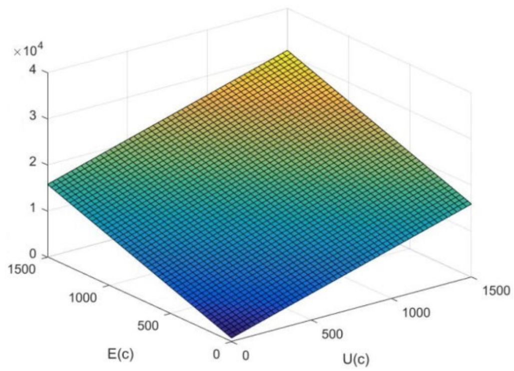

FIGURE 10. Influence of technical level and social effect on the overall revenue of the co-symbiosis system.

C. SYNERGISTIC SYSTEM INFLUENCING FACTORS

Fig.7-10 shows the influence of government behavior and social additional benefits on the parameters of the co-symbiosis R&D system.

According to Fig. 7 and Fig. 8, the technical level of collaborative innovation R&D system increases with the increase of government subsidies to enterprises. In addition, the higher the government subsidies, the more obvious the technological level. The social effect brought by the system is also the increasing function of the government's reward for enterprises to fulfill their social responsibility. The government pursuits the good vision of social development and progress. It plays an important role in guiding enterprises to fulfill

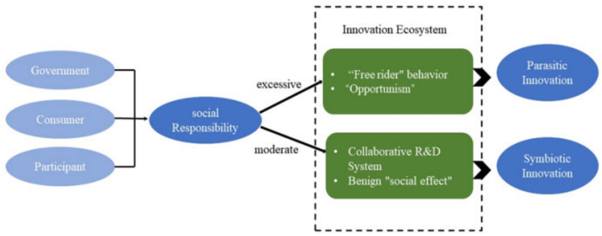

FIGURE 11. Impact of social responsibility on innovation ecosystem.

their social responsibility. Appropriate fulfillment of social responsibilities is conducive to the sound development of the innovation ecosystem. It will help the system to give full play to the dual effectiveness of innovation and society. It verifies that government behavior plays an important role in regulating and encouraging collaborative innovation R&D system.

Fig. 9 shows the positive cyclical value of social effects. When the enterprise behavior formed a certain social effect, enterprises can get a good corporate image and reputation. And thus build and maintain quality social networks. Then they can obtain information resources, technical resources, knowledge resources and so on. It is conducive to improving the innovation ability, market competitiveness and influence of enterprises. Therefore, it will lead to the increase of its accessory rate of return, then bring better social effect for the enterprises.

As can be seen from the Fig. 10. On the impact on the over-all revenue of co-symbiosis R&D system, both technical level and social effect play a key role. They raise the overall level of revenue together. Both enterprise development and innovation ecosystem upgrading need to be balanced driven by technological innovation and social responsibility.

VIII. CONCLUSION

From the perspective of social responsibility paradox, this paper tries to embed the factors of social responsibility into the R&D system. Then combines the concept of competition and co-existence in the innovation ecosystem. By means of differential game theory, the decision-making behavior and social effect of enterprises in innovation ecosystem are researched. The innovation ecosystem has both technological innovation and social development effects. It can improve the efficiency of innovation and enterprise income effectively. But that will trigger a contradiction inevitably. The innovation ecosystem is dominated by core enterprise. Then it will evolves into a decentralized structure, which is the idealized state. Innovation ecosystem advocates the realization of symbiosis and win-win among members. However, when considering embedded social utility, the paradox of social responsibility provides more uncertainty for the R&D system. This paper considered the complexity of core technology R&D and social relationship. Then, a dynamic decision-making process model were constructed under three scenarios: non-cooperative independent R&D, master-slave R&D dominated by core enterprises and co-symbiosis R&D. Finally, we compared and analyzed the results through simulation. The main conclusions are as follows:

(1) Co-symbiosis is the best way for enterprises to enhance innovation ability and gain competitive advantage. Supporting enterprises are not only responsible for technical assistance and resource supply, but also carry out independent R&D actively. In addition to core technology R&D, social responsibility is also crucial in competition. Social responsibility practices can bring a good image and reputation to an enterprise. This can help expand access to resources and maintain social networks. On this basis, the cost of enterprise innovation will be reduced. Besides, the improvement of consumer market recognition brings the irreplaceable social effect for enterprises. The profit of enterprises increase because of the combined action of cost and social effect. Finally, the enterprises and systems will develop healthily.

(2) The government encourages the realization of enterprise value and social value. Benign auxiliary measures help to improve the enterprise's enthusiasm to meet social expectations. This will encourage companies to balance core technology R&D with social responsibility practices. Symbiotic evolution is the ultimate demand of innovation ecosystem development. The government is the champion of innovation model of co-symbiosis. Combined with the simulation results in this paper, it can be found that: Symbiotic innovation is the highest level of efforts to improve the technical level and social responsibility. Moderate implementation of social responsibility can improve the technical level, social effect and income of innovation system. However, the social responsibility paradox emphasizes that the system has a risk of imbalance. In other words, the dominant enterprise supports the weak enterprise excessively. It will encourage the "free rider" behavior. Chose low earnings ratio help core enterprise to establish a high-quality corporate image. Excessive pursuit of social value is contrary to the target of profit maximization. It not only hinders own development, but also promotes the master-slave innovation to parasitism. Then damages the balance of entire innovation ecosystem. For government, the subsidy to supporting enterprise should also be appropriate. When the subsidy is too high, supporting enterprise will be attached to the additional subsidy income which is provided by government. This will inhibit the initiative of independent innovation. Parasitic situation will be formed over time. As we all know, parasitic means that the innovation ecosystem cannot be sustainable.

(3) Enterprise innovation value and social value are coupled. There is a harmonious and mutually beneficial relationship between them. Innovation value is the foundation of an enterprise. Social value is the stem and leaf of an enterprise. Only when considering both can you blossom and bear fruit. Multiple situational requirements impact the independent and internalized enterprise innovation model constantly. Such as technological mutation, user individuation and market diversification. It is inevitable for enterprises to rely on innovation ecosystem to enhance their

competitive advantage. At this time, co-symbiosis is the best choice for enterprises. Co-symbiosis requires enterprises to pursue social value appropriately while laying a solid technical foundation. Mutualism advocates the maximization of overall interests. Innovation ecosystem theory emphasizes the enterprises are no longer independent individuals. Enterprises are part of the system. The additional revenue brought by the system will be distributed to each enterprise in proportion. This paper found that: The higher R&D subsidy from government to supporting enterprise, the higher earnings ratio of the enterprise. In other words, the marginal benefit of supporting enterprise is higher than core enterprise. As far as the core enterprise is concerned, the proportion of additional income decreased. But the amount of income increased. Due to the characteristic of innovation ecosystem is "$1+1 \gg 2$". A benign system can bring higher additional benefits to the enterprise. Because of the cost cutting, convenience of resources and so on. These factors improve the efficiency of enterprise innovation. Ultimately, it increases the profit of core enterprise.

To sum up, social responsibility helps to improve the overall returns of R&D system in the innovation ecosystem. But the enterprises cannot ignore the hidden risks brought by the social responsibility paradox(Fig.11). The necessary conditions for enterprise development include moderate social responsibility practice and core technology foundation. Synergistic symbiosis can help profit and social value reach Pareto optimality. Once beyond the scope of benign social responsibility practice, it will improve the probability of opportunism greatly. "Free riding" behavior leads to a parasitic rather than symbiotic system. As a result, the innovation ecosystem will out of balance and unsustainable.

This paper analyzed the enterprise R&D strategy and influencing factors from the perspective of social responsibility paradox by means of differential game. But both the social responsibility and innovation ecosystem are complex concepts. In the future, the influence mechanism of more influence parameters should be studied. At the same time, research should describe the social responsibility paradox in detail. Analyze the coupling and conflict between technological innovation and social responsibility concretely. And should extend to multiple types of decision-making subjects. We hope the optimal equilibrium strategy will be further explored.

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