Differential Game Analysis of Enterprises Investing in New Infrastructure and Maintaining Social Network Security Under the Digital Innovation Ecosystem

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**ABSTRACT** With the new round of industrial and technological revolution in China, the new normal of the Chinese economy is increasingly in the form of a digital economy characterized by continued growth and development potential. The digital economy has become an important engine driving the growth of the Chinese economy. The digital transformation of enterprises is a hot topic and poses a difficult research problem. More importantly, ensuring the security of digitalization has become a common challenge faced by society. This paper analyzes the value composition of the digital innovation ecosystem and uses differential game theory to explore the optimal decision-making of leading enterprises and following enterprises in terms of digital innovation and social responsibility under different circumstances. The results show that in the digital innovation ecosystem, (1) leading enterprises and following enterprises have the least income, the weakest degree of digital innovation, and the weakest ability to maintain social network security under non-cooperative conditions; (2) overall income will increase over time, and digital innovation and the maintenance of social network security have a positive effect on the development of the digital economy; (3) the government encourages enterprises to develop digital innovation and maintain social network security and provides appropriate subsidies to some extent, which boosts the development of enterprises.

**INDEX TERMS** Digital innovation ecosystem, digital transformation, new infrastructure, social network security, differential game.

**I. INTRODUCTION** With the rapid development of the new economic form of a digital economy, the operation mode of enterprises is undergoing substantial changes. The 2019 G20 Principles on High Quality Infrastructure Investment emphasizes the role of investment in high-quality infrastructure in promoting sustainable development, placing sustainable development at the top of the “Six Principles”, which have been widely recognized by G20 members. The digital economy drives the deep penetration and wide application of emerging digital technologies to different industries, such as cloud computing, 5G, big data, artificial intelligence, blockchain and the Internet of Things [1], and it accelerates the digital transformation of traditional enterprises [2]. The continuous innovation and transformation of enterprise production modes is an important characteristic of sustained and vigorous economic development. The digital economy will certainly be the development trend in the future, which will inject considerable energy into promoting the free flow and effective use of social resources and high-quality economic development [3]. In particular, traditional enterprises’ transformation of development mode, change of production environment, value creation mode and inter-enterprise relationship [4] are
of great relevance to realizing the digital transformation and high-quality development of the Chinese economy [5]. Experience has shown that the success of digital transformation depends on the reserve degree of new infrastructure and the security of the social network [6]. New infrastructure is the backbone of the digital economy and the structural support for the digital age, and developing this infrastructure can provide opportunities for digital transformation and support the competitive position of enterprises. In the digital innovation ecosystem, enterprises with abundant new infrastructure are regarded as leading enterprises, while traditional enterprises with relatively weak reserves of new infrastructure are regarded as following enterprises. A leading enterprise is a resource center in the digital innovation ecosystem, and its decisions affect the degree of digitization of following enterprises even the entire innovation system. Following enterprises realize transformation and upgrading through integration with digital technology, which can improve the trading environment, trading time and decision-making range of both supply and demand; reduce the comprehensive expenses of enterprises; and improve their production and operation efficiency to a certain extent. Therefore, understanding how to ensure that leading enterprises lead the digital transformation of following enterprises and drive the overall growth of the economy has become an urgent problem for the digital innovation ecosystem. At the same time, the development of digital innovation will inevitably generate prominent social network security problems. Currently, big data are widely used in various applications, such as organization business support, operation decision-making and evaluation, product innovation research and development, and external enterprise cooperation. Data connect each relevant subject and facilitate synergy among organizations throughout the digital innovation ecosystem. Data security is thus the main concern related to social network information security, and it is also a crucial part of ensuring the safe development of the digital economy. Therefore, it is vital to explore ways for the government and enterprises to accelerate the improvement of the data information security management system to ensure the security of social network information.

In summary, there are leading enterprises, following enterprises and governments in the digital innovation ecosystem. Leading enterprises, as the forerunner of digital transformation, determine the level of their own digital expansion and maintenance of network security costs. Following enterprises, as the latecomers of digital transformation, determine the cost and means of digital transformation and maintenance of network security. Both sides have competition and cooperation opportunities. The government, as the supporting force of digital transformation, provides subsidies for enterprises to bear the costs. Based on the level of government subsidies, both leading and following enterprises will make decisions for the purpose of maximizing profits. Therefore, starting from the game relationship between leading enterprises and following enterprises, this paper embeds factors from social responsibility level into a game model of the digital transformation of enterprises, analyzes the optimal solution of the two types of enterprises in three game situations, and then explores the solution that maximizes the overall benefits of the digital ecosystem.

II. THEORETICAL BASIS AND RESEARCH FRAMEWORK

A. RESEARCH ON THE DIGITAL INNOVATION ECOSYSTEM

The concept of an innovation ecosystem emphasizes that many participants take one subject as the core focus and jointly produce new technologies, new formats and new models through competition and cooperation or coupling, thus realizing the nonlinear interaction relationship of value co-creation [7]–[9]. Digital innovation refers to the introduction of digital technology into the product creation and business operation processes of enterprises [10]. The digital innovation ecosystem is formed by the combination of an innovation ecosystem and digital innovation [11], and it is a complex network relationship of dynamic competition and cooperation generated by the participation of all subjects in digital innovation [12], [13]. Through mutual interaction, system efficiency is improved, resources are shared, and internal and external collaboration as well as system innovation are promoted [14]. The participants are usually composed of heterogeneous digital elements, suppliers and demanders [15], which can include digital leading enterprises, digital following enterprises, digital technology sharing platforms [16], and governments. Digital innovation and transformation rely on the support of the digital innovation ecosystem because the modular digital platform and digital infrastructure are important technical frameworks and coordination tools in the ecosystem [17], which not only contribute to the development and growth of digital leading enterprises but also become the only means of digital transformation among traditional enterprises. Many scholars in China and abroad have categorized the driving factors of digital transformation into three factors: senior management, digital technology [18] and industrial clusters [19]. A series of studies have shown that digital technology will affect the business process of enterprises and thus influence the overall benefit to society. With the deepening of collaborative innovation theory, scholars in China and abroad have discussed problems related to the enterprise relationship between members of the innovation ecosystem. The researchers divided the relationship between leading enterprises and following enterprises into two types: following enterprises dominated by leading enterprises, the master–slave type, and the non-dominant, symbiotic type. Leading enterprises with a rich digital technology tradition were regarded as key players in the digital innovation ecosystem and “assistants” of traditional enterprises in digital transformation [15]. With their own keen industry insight, leading enterprises can boost the digital transformation of following enterprises to achieve a win–win situation [20]. Many scholars asserted that digital transformation emphasizes the diversification of the subject: there must be both intensive development of digital technology by leading enterprises and a physical platform to broaden the number of...
B. RESEARCH ON NEW INFRASTRUCTURE INVESTMENT IN DIGITAL INNOVATION

In the digital innovation ecosystem, the new infrastructure is an important digital element; it is essentially different from the “iron public base” and “traditional infrastructure”, and it can reduce costs and improve efficiency by connecting resource flows across the system. The digital infrastructure is mainly based on 5G, AI, Internet of Things, blockchain, cloud computing, industrial internet, data centers, fixed broadband and other new components of infrastructure. [24]. The first characteristic of investment in new infrastructure is that leading enterprises are the main investment subjects; the second characteristic is that the investment object includes both hard facilities and software facilities; and the third characteristic is that investment projects are not one-time endeavors but continue to invest in supporting updates and new iterations [25]. The new infrastructure is the intersection and integration of commercial infrastructure, public infrastructure and social infrastructure. It not only promotes the digital transformation and upgrading of enterprises but also provides technical support for the improvement of social services and public governance efficiency [26]. According to the relevant data issued by the National Development and Reform Commission, J. T. Tian and D. L. Yan divided new infrastructure into three aspects—information infrastructure, integrated infrastructure and innovation infrastructure—and suggested that the new infrastructure serves as a national “highway” to facilitate the development of the digital economy, representing the core element to promote the digital transformation [27]. New infrastructure has a powerful role in supporting the digital economy and is continually upgraded. In terms of the impact on enterprises, the advantages of investing in new infrastructure are as follows: First, this infrastructure can support breakthroughs in the development of important core technologies, alleviate the technological decoupling caused by dependence on foreign technologies, reduce the cost of digital leading enterprises, accelerate the process of realizing self-sufficiency and increase economic benefits. Second, traditional following enterprises can be upgraded with new technologies to promote digital transformation and enhance the endogenous power of enterprises [28]. To further explore the value of investment in new infrastructure, C. X. Guo, J. Q. Wang and H. R. Liu used the input–output method to calculate the investment multiplier of new infrastructure and pointed out that new infrastructure could drive agriculture, the light textile industry and technology-intensive manufacturing industry better than traditional infrastructure [29]. F. Q. Liu and C. C. Su also found that new infrastructure could promote the integrated development of industries, drive and lead the upstream and downstream demands of industries, enable different industries to merge to form new industrial clusters, and promote economic development to form spillover effects [30]. With respect to exploring the development of new infrastructure, the government also forcefully supports the digital transformation of enterprises. By lowering the standards for investment in new infrastructure and providing tax incentives and financing, the government supports and guides enterprises to invest in new infrastructure. In China, cooperation between the government and social capital is called the public private partnership (PPP), which refers to the long-term and complex cooperation between government departments and enterprises for the purpose of providing infrastructure and public services [31]. In this model, the government encourages or authorizes enterprises to invest in construction and operation, and the two sides share benefits and risks to achieve the ultimate goal. However, some scholars have noted shortcomings of the current new infrastructure in China. First, the investment scale is insufficient and uneven, which makes it difficult to achieve a cluster effect. Second, the construction of soft and hard components of the new infrastructure is imbalanced, focusing on hardware facilities such as 5G base stations while ignoring the construction of social facilities such as information system software and legal regulations. Third, the new infrastructure depreciates quickly and may not play a substantial role in promoting long-term and sustainable economic development. Fourth, the new infrastructure is rife with social network information security problems.

C. ELABORATION ON ISSUES RELATED TO MAINTAINING SOCIAL NETWORK SECURITY IN DIGITAL INNOVATION

Network security is a balance between risk and control with the accumulation of rich knowledge and experience. With the spread of the new infrastructure and the wide application of digital technology, the phenomenon of network security risk becomes intensified in society. Network security issues are key concerns among the problems associated with the development of the digital innovation ecosystem. Hence, governments and enterprises must scientifically and comprehensively build and improve the network security technology and the management and operation of the unified system to ensure that the digital economy develops healthily and steadily. The most typical embodiment of social network security is data security, as data is seen as a factor of production and its operation and management [22]. For example, Y. Q. Chi, F. Liu and et al. have noted shortcomings of the current new infrastructure in terms and sustainable economic development. Fourth, the new infrastructure is rife with social network information security problems.

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J. Y. Qi determined that leading enterprises with data-driven operation modes are no longer limited to internet enterprises but also include traditional following enterprises. In a time in which “those who get data get the world”, the premise of robust enterprise operations and social digital economic stability is to achieve effective protection and efficient use of data [34]. A number of scholars concluded that proper data management is the key to the success of enterprises and governments [35]. In the digital innovation ecosystem, the internet, finance, medical care, government and many other industries are concerned with the security data generation, privacy, storage and other aspects. Once a data leakage occurs, the enterprise’s profit margin, stock price and brand image will suffer a major impact while endangering the network information security of the society.

Therefore, to realize the healthy development of a digital innovation ecosystem, it is essential to maintain social network security. Currently, the domestic leading enterprises tend to value technology but ignore its management, failing to take responsibility for protecting the safety of the social network. Leading enterprises, as a leader in mature technologies, need to take on the burden of maintaining network security. For example, the international internet company Yahoo has regulated the management of the company’s network information security and implemented standardized management [36]. However, traditional following enterprises in digital transformation have difficulty providing network security due to their own technological limitations, so they need to adjust their operation mode to keep up with the pace of digital transformation.

D. LITERATURE REVIEW AND RESEARCH FRAMEWORK

Based on the above background, it can be seen that scholars have carried out certain studies on new infrastructure and social network security issues under the digital innovation ecosystem and achieved certain results. However, from the analysis of influencing factors, the research on the combination of enterprises’ investment in new infrastructure and the maintenance of social network security has not been in depth. Especially in the maintenance of social network security, the research on how to make optimal decisions among enterprises is very sparse. Facing the impact of the current severe situation of the COVID-19 pandemic, the speed of internet development has increased considerably, and uncertainties in the digital innovation system have become increasingly complex. Enterprises should pay equal attention to technology and security so as to more effectively promote the development of enterprise digital transformation [37]. Therefore, it is particularly critical to study how enterprise clusters coordinate to promote digital innovation [38], [39].

Differential game models are suitable for the study of decision-making problems in a continuous time game. This paper introduces the maintenance of social network security factors, builds a differential equation describing new infrastructure investment under different conditions, and analyzes the dominance of digital leading enterprises and the non-dominant symbiotic type of digital innovation to explore the benefits of new infrastructure investment. Considering the obligation of maintaining social network security, the benefit gap between the master–slave model and the symbiotic model is compared in order to provide support and reference for enterprises to improve their investment strategies in the digital innovation ecosystem.

III. PROBLEM DESCRIPTION

Based on the dynamic perspective and the method of differential games, this paper studies the investment in new infrastructure and the maintenance of network information security of the participants in the digital innovation ecosystem by taking the completely rational leading enterprises and following enterprises as the main research objects. Among them, leading enterprises have mature digital technology and the strength to support the completion of new infrastructure investment by themselves and can lead the transformation of following enterprises’ investments. Following enterprises can undertake digital transformation on the basis of giving full play to the functions of traditional enterprises, invest in new infrastructure and accumulate digital technology. As the guardian of the digital innovation ecosystem, the government will introduce incentives for enterprises to invest in new infrastructure and give appropriate incentives to enterprises that maintain social network security so as to jointly ensure the healthy and high-quality development of the digital economy. According to the above problem description, the Hamilton–Jacobi–Bellman equation (HJB) is used to investigate the optimal returns of leading enterprises and following enterprises under different relationship conditions. First, a Nash non-cooperative game model with non-cooperative forms independently operated by both parties is established to provide a comparative reference for subsequent research. In the process of collaborative digital transformation, if the leading enterprise is in the core position and the following enterprise has weak autonomy and the leading enterprise bears part of the investment in new infrastructure and maintenance of network security costs for the following enterprise, the relationship is in accordance with Stackelberg master–slave game model. If there is no master–slave difference between the two enterprises and they adopt equal symbiotic operation, the relationship conforms to a non-dominant symbiotic game model. By analyzing and comparing the enthusiasm of enterprises on both sides to invest in new infrastructure and their efforts to maintain network security under different relationships, this paper summarizes the game scheme that can achieve the optimal overall benefit of the digital ecosystem, and finally verifies it through simulation analysis, in order to provide reference for digital transformation. The relationship between leading and following enterprises and the government is inseparable, as shown in Fig. 1.

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IV. MODEL CONSTRUCTION AND ANALYSIS

A. MODEL ASSUMPTIONS

Assuming that the leading enterprise \( (M) \) and the following enterprise \( (N) \) make rational and independent decisions, the cost paid by the two enterprises in investing in new infrastructure is positively related to the degree of efforts to maintain social network security. Therefore, the cost function of investing in new infrastructure is \( C_i(B_i(t)) = \frac{\mu_i B_i^2(t)}{2} \) \((i = M, N)\). Similarly, the cost paid by enterprises to maintain social network security is positively related to the degree of efforts to maintain social network security, so the cost function obtained is \( C_i(S_i(t)) = \frac{\mu_i S_i^2(t)}{2} \) \((i = M, N)\). In the formula, \( \mu_i \) and \( \mu_i \) respectively represent the cost coefficient of enterprise’s investment in new infrastructure and the cost coefficient of enterprise’s maintenance of social network security \((0 \leq \mu_B < 1, 0 \leq \mu_S < 1)\).

In the digital innovation ecosystem, the digital transformation is a dynamic process. Leading enterprises and following enterprises engage in resource sharing and collaborative innovation, representing a new type of infrastructure investment to produce more, and maintain social network security through additional mutual benefits. The differential equation for participation in this collaborative innovation process is as follows:

\[
\dot{G}(t) = \frac{dG(t)}{dt} = (r_M + q_M)B_M(t) + (r_N + q_N)B_N(t) - \phi G(t) \\
\dot{J}(t) = \frac{dJ(t)}{dt} = (f_M + j_M)S_M(t) + (f_N + j_N)S_N(t) - \theta J(t)
\]

In the formula, \( G(t) \) represents the technical reserve level of new infrastructure possessed by the enterprise at time \( t \), \( J(t) \) represents the social achievements brought by the enterprise maintaining social network security at time \( t \), \( r_i \) represents the degree of influence of the initiative to increase the number of new infrastructure on digital transformation \((i = M, N)\), \( q_i \) represents the degree of influence of the enterprise’s initiative to improve the quality of new infrastructure on digital transformation \((i = M, N)\), \( f_i \) represents the impact of the enterprise’s efforts to improve data mining technology on social network security achievements \((i = M, N)\), \( j_i \) represents the degree of impact of enterprise’s efforts to enhance data management technology on social network security achievements \((i = M, N)\), \( \phi \) represents the depreciation rate of iteration upgrading of new infrastructure \((\phi > 0)\), and \( \theta \) represents the inhibiting effect of excessive policy control on social network security issues on enterprise digital transformation \((\theta > 0)\).

B. GAME MODEL CONSTRUCTION AND SOLUTION ANALYSIS

Based on the above assumptions and without considering other relevant relationships of the digital innovation ecosystem system, and referring to the objective function setting method in the differential game, the decision-making problems of both enterprises are set as follows:

\[
Z_M = \max_{R_M \geq 0, S_M \geq 0} \int_0^{+\infty} e^{-\rho t} \left[ k\pi(t) - \frac{\mu B_M}{2} (1 - a_M)B_M^2 - \frac{\mu S_M}{2} (1 - h_M)S_M^2 \right] dt
\]
Z_{N} = \max_{B_{N} \geq 0, S_{N} \geq 0} \int_{0}^{+\infty} e^{-\mu t} \times \left[ (1-k)\pi(t) - \frac{\mu B_{N}}{2} (1-a_{N}) B_{N} - \frac{\mu S_{N}}{2} (1-h_{N}) S_{N} \right] dt \tag{4}

Among them, the overall benefit \( \pi(t) = \pi_{0} + \sigma G(t) + \varepsilon J(t) (G \geq 0, J \geq 0, \pi_{0} \geq 0) \). In the formula, governments and enterprises have the same discount rate \( \rho (\rho > 0) \) at any given time, the proportion of the leading enterprise in the overall revenue is \( k \), the policy subsidy rate of government support for enterprise investment in new infrastructure is \( a_{i} (i = M, N) \), the subsidy rate of government to enterprises for maintaining social network security is \( h_{i} (i = M, N) \), \( \sigma \) represents the influence of an enterprise’s enthusiasm to invest in new infrastructure on total revenue, and \( \varepsilon \) represents the impact of the enterprise’s efforts in maintaining social network security on the total revenue.

C. NASH NON-COOPERATIVE GAME CASE SCENARIO

**Theorem 1:** Assuming that in the non-cooperative situation without cost sharing, both enterprises make independent decisions and aim at benefit maximization. In this case, the optimal strategies are respectively as follows: \((B_{M}^{n}, S_{M}^{n})\), \((B_{N}^{n}, S_{N}^{n})\)

\[
\begin{align*}
B_{M}^{n} &= \frac{k(r_{M} + q_{M})\sigma}{\mu_{B_{M}}(1 - a_{M})(\rho + \phi)}, \quad \quad S_{M}^{n} = \frac{k(j_{M} + j_{M})\varepsilon}{\mu_{S_{M}}(1 - h_{M})(\rho + \theta)} \tag{5} \\
B_{N}^{n} &= \frac{(1-k)(r_{N} + q_{N})\sigma}{\mu_{B_{N}}(1 - a_{N})(\rho + \phi)}, \quad \quad S_{N}^{n} = \frac{(1-k)(f_{N} + j_{N})\varepsilon}{\mu_{S_{N}}(1 - h_{N})(\rho + \theta)} \tag{6}
\end{align*}
\]

**Proof:** The bounded differential function of both benefits is constructed as \( W_{i}(G, J) i \in (M, N); \) for all \( G \geq 0, J \geq 0 \), the enterprise’s HJB equation is satisfied:

\[
\rho W_{M}(G, J) = \max_{B_{M} \geq 0, S_{M} \geq 0} \left[ \begin{align*}
&[k(\pi_{0} + \sigma G + \varepsilon J) - \frac{1}{2}(1 - a_{M})\mu_{B_{M}}B_{M}^{2} - \frac{1}{2}(1 - h_{M})\mu_{S_{M}}S_{M}^{2} + \frac{\partial W_{M}}{\partial G} [(r_{M} + q_{M}) B_{M} + (r_{N} + q_{N}) N_{B} - \phi G] + \frac{\partial W_{M}}{\partial J} [(j_{M} + j_{M}) S_{M} + (f_{N} + j_{N}) S_{N} - \theta J] \\
&\rho W_{N}(G, J) = \max_{B_{N} \geq 0, S_{N} \geq 0} \left[ \begin{align*}
&[k(\pi_{0} + \sigma G + \varepsilon J) - \frac{1}{2}(1 - a_{N})\mu_{B_{N}}B_{N}^{2} - \frac{1}{2}(1 - h_{N})\mu_{S_{N}}S_{N}^{2} + \frac{\partial W_{N}}{\partial G} [(r_{M} + q_{M}) B_{M} + (r_{N} + q_{N}) N_{B} - \phi G] + \frac{\partial W_{M}}{\partial J} [(j_{M} + j_{M}) S_{M} + (f_{N} + j_{N}) S_{N} - \theta J]
\end{align*} \right]
\end{align*} \right] \tag{7}
\]

Take the first-order partial derivatives of \((B_{M}, S_{M})\) and \((B_{N}, S_{N})\) on the right sides of (7) and (8) respectively, and make their right ends equal to 0, and the independent optimal decision can be obtained:

\[
(B_{M}, S_{M}) = \left( \frac{(r_{M} + q_{M}) \frac{\partial W_{M}}{\partial G}}{(1 - a_{M})\mu_{B_{M}}}, \frac{(j_{M} + j_{M}) \frac{\partial W_{M}}{\partial J}}{1 - a_{M})\mu_{B_{M}}} \right) \tag{9}
\]

\[
(B_{N}, S_{N}) = \left( \frac{(r_{N} + q_{N}) \frac{\partial W_{N}}{\partial G}}{(1 - a_{N})\mu_{B_{N}}}, \frac{(f_{N} + j_{N}) \frac{\partial W_{N}}{\partial J}}{(1 - a_{N})\mu_{B_{N}}} \right) \tag{10}
\]

By substituting (9) and (10) into (7) and (8), the following can be obtained:

\[
\rho W_{M}(G, J) = k\pi_{0} + \left( 1 - k \sigma - \phi \frac{\partial W_{M}}{\partial G} \right) G
\]

\[
+ \left( k\varepsilon + \theta \frac{\partial W_{M}}{\partial J} \right) J + \left( \frac{(r_{M} + q_{M}) \frac{\partial W_{M}}{\partial G}}{2\mu_{B_{M}}(1 - a_{M})} \right)^{2}
\]

\[
+ \left( \frac{(j_{M} + j_{M}) \frac{\partial W_{M}}{\partial J}}{2\mu_{B_{M}}(1 - a_{M})} \right)^{2}
\]

\[
+ \left( \frac{(r_{N} + q_{N}) \frac{\partial W_{N}}{\partial G}}{\mu_{B_{N}}(1 - a_{N})} \right)^{2}
\]

\[
+ \left( \frac{(f_{N} + j_{N}) \frac{\partial W_{N}}{\partial J}}{\mu_{S_{N}}(1 - h_{N})} \right)^{2}
\]

\[
\rho W_{N}(G, J) = (1 - k)\pi_{0} + \left( 1 - k \sigma - \phi \frac{\partial W_{N}}{\partial G} \right) G
\]

\[
+ \left( (1-k)\varepsilon + \theta \frac{\partial W_{N}}{\partial J} \right) J
\]

\[
+ \left( \frac{(r_{N} + q_{N}) \frac{\partial W_{N}}{\partial G}}{2\mu_{B_{N}}(1 - a_{N})} \right)^{2}
\]

\[
+ \left( \frac{(f_{N} + j_{N}) \frac{\partial W_{N}}{\partial J}}{2\mu_{B_{N}}(1 - a_{N})} \right)^{2}
\]

\[
+ \left( \frac{(r_{M} + q_{M}) \frac{\partial W_{M}}{\partial G}}{\mu_{B_{M}}(1 - a_{M})} \right)^{2}
\]

\[
+ \left( \frac{(f_{M} + j_{M}) \frac{\partial W_{M}}{\partial J}}{\mu_{S_{M}}(1 - h_{M})} \right)^{2}
\]

\[
\]

According to the functional form of (11) and (12), the solution of the binary first-order function equation of \( G \) and \( J \) can be set as follows:

\[
W_{M}(G, J) = a_{1}G + \beta_{1}J + \eta_{1} \tag{13}
\]

\[
W_{N}(G, J) = a_{2}G + \beta_{2}J + \eta_{2} \tag{14}
\]

where \( a_{1}, a_{2}, \beta_{1}, \beta_{2}, \eta_{1} \) and \( \eta_{2} \) are all constants. The partial derivatives of \( W_{M}(G, J), W_{N}(G, J), G \) and \( J \) are substituted into (9) and (10) to obtain, (15) and (16), as shown at the bottom of the next page.

By substituting the above parameter values into (9) and (10), the optimal equilibrium strategy of (5) and (6) can be obtained. By substituting (5) and (6) into (1) and (2), the optimal trajectory for realizing the benefits of investing in new infrastructure and maintaining social network security
can be obtained:

\[ G^n = e^{-\phi t}(G_0 - I_1) + I_1 \]
(17)

\[ J^n = e^{-\beta t}(J_0 - I_2) + I_2 \]
(18)

Among them,

\[
\begin{cases}
I_1 = \frac{\sigma k(r_M + q_M)^2}{\phi \mu_B(M(1 - a_M)(\rho + \phi)} + \sigma(1 - k)(r_N + q_N)^2 \mu_B(1 - a_N)(\rho + \phi) \\
I_2 = \frac{\varepsilon k(f_M + j_M)^2}{\theta \mu_S(1 - h_M)(\rho + \theta)} + \varepsilon(1 - k)(f_N + j_N)^2 \theta \mu_S(1 - h_N)(\rho + \theta)
\end{cases}
\]

By substituting the parameter values in (15) and (16) into (13) and (14), the optimal function of enterprises of both sides can be obtained, and then the optimal value of total profit in the digital innovation ecosystem under Nash game is

\[
W^n = \frac{\sigma}{\rho + \phi} G^n + \frac{\varepsilon}{\rho + \theta} J^n + \frac{\pi_0}{\rho}
\]
\[ + \frac{k(2 - k)(r_M + q_M)^2}{2\phi \mu_B(M(1 - a_M)(\rho + \phi)} + \frac{(1 - k^2)(r_N + q_N)^2}{2\phi \mu_B(1 - a_N)(\rho + \phi)} \sigma^2
\]
\[ + \frac{k(2 - k)(f_M + j_M)^2}{2\varepsilon \mu_S(1 - h_M)(\rho + \theta)} + \frac{(1 - k^2)(f_N + j_N)^2}{2\varepsilon \mu_S(1 - h_N)(\rho + \theta)} \varepsilon^2
\]
(19)

End of proof.

**D. STACKELBERG MASTER–SLAVE GAME SCENARIO**

In Stackelberg master–slave game scenario, leading enterprises play a core role in the digital innovation ecosystem. To encourage enterprises to follow the digital transformation, leading enterprises will share part of the cost of investment in new infrastructure with the proportion of \(x_B\) while, at the same time, bearing the cost of maintaining social network security with the proportion of \(x_S\). In this case, the leading enterprise will determine its own optimal decision \((B_M^*, S_M^*)\), and the following enterprise will make its own optimal decision \((B_N^*, S_N^*)\) according to the decision of the leading enterprise. The objective function of enterprise \(M\) and enterprise \(N\) is

\[
Z_M = \max_{B_M \geq 0, S_M \geq 0} \int_0^{+\infty} e^{-\rho t} \left[ (1 - k)\pi(t) - \frac{\mu_B}{2} (1 - a_M) B_M^2 \right. \]
\[ - \frac{\mu_M}{2} (1 - h_M) S_M^2 \]
\[ - \frac{\mu_B x_B}{2} (1 - a_N) B_N^2 \]
\[ - \frac{\mu_S x_S}{2} (1 - h_N) S_N^2 \]
\[ \left. dt \right] \]
(20)

\[
Z_N = \max_{B_N \geq 0, S_N \geq 0} \int_0^{+\infty} e^{-\rho t} \left[ (1 - k)\pi(t) - \frac{\mu_B}{2} (1 - a_N) B_N^2 \right. \]
\[ - \frac{\mu_B x_B}{2} (1 - a_N) B_N^2 \]
\[ - \frac{\mu_S x_S}{2} (1 - h_N) S_N^2 \]
\[ \left. dt \right] \]
(21)

**Theorem 2:** Assuming that the optimal strategy of both enterprises in Stackelberg master–slave game is

\[
B_M^* = \frac{k(r_M + q_M)\sigma}{\mu_B(1 - a_M)(\rho + \phi)}, \quad S_M^* = \frac{k(f_M + j_M)\varepsilon}{\mu_S(1 - h_M)(\rho + \theta)}
\]
(22)

\[
B_N^* = \frac{((N + q_N)\sigma)[2k + (1 - k)(1 - a_N)]}{2\mu_B(1 - a_N)^2(\rho + \phi)}, \quad S_N^* = \frac{(f_N + j_N)\varepsilon[2k + (1 - k)(1 - h_N)]}{2\mu_S(1 - h_N)^2(\rho + \theta)}
\]
(23)

\[
x_B^* = \frac{2k(1 - a_N)(1 - k)(1 - a_N)^2}{2k + (1 - k)(1 - a_N)}, \quad 1 - a_N < k < 1
\]
(24)

\[
x_S^* = \frac{2k(1 - h_N)(1 - k)(1 - h_N)^2}{2k + (1 - k)(1 - h_N)}, \quad 1 - h_N < k < 1
\]
(25)
When
\[ 0 < k < \frac{1 - a_N}{3 - a_N}, \quad x_B^S = 0; \]

When
\[ 0 < k < \frac{1 - h_N}{3 - h_N}, \quad x_S^S = 0; \]

**Proof:** Following enterprises can accurately predict the optimal decision choices of leading enterprises and make their own strategies according to the strategies formulated by leading enterprises and the proportion of costs borne by them. The bounded differential function of both benefits is denoted as \( W_i(G, J) \) for all \( G \geq 0, J \geq 0 \), the enterprise’s HJB equation is satisfied:

\[
\rho W_m(G, J) = \max_{B_m \geq 0, S_m \geq 0} \left[ k (\pi_0 + \sigma G + eJ) - \frac{\mu_{B_m}}{2} (1 - a_m) B_m^2 - \frac{\mu_{S_m}}{2} (1 - h_m) S_m^2 \right] + \frac{\partial W_m}{\partial G} (r_m + q_m) B_m + (r_N + q_N) B_N - \phi G + \frac{\partial W_m}{\partial J} (f_m + j_m) S_m + (f_N + j_N) S_N - \theta J \right]
\]

(26)

The first-order partial differential equations of (26) and (27) with respect to \( (B_m, S_m) \) and \( (B_n, S_n) \) can be obtained:

\[
(B_m, S_m) = \left( \frac{r_m + q_m}{\mu_{B_m}(1 - a_m)}, \frac{f_m + j_m}{\mu_{S_m}(1 - h_m)} \right)
\]

(28)

\[
(B_n, S_n) = \left( \frac{r_n + q_n}{\mu_{B_n}(1 - a_n - x_B)}, \frac{f_n + j_n}{\mu_{S_n}(1 - h_n - x_S)} \right)
\]

(29)

\[
x_B = \frac{2 - (a_n) \left( \frac{\partial W_m}{\partial G} \right) - (1 - a_n)^2 \left( \frac{\partial W_n}{\partial G} \right)}{2 \left( \frac{\partial W_m}{\partial J} \right) + (1 - a_n) \left( \frac{\partial W_m}{\partial G} \right)}
\]

(30)

\[
x_S = \frac{2 - (h_n) \left( \frac{\partial W_m}{\partial J} \right) - (1 - h_n)^2 \left( \frac{\partial W_m}{\partial J} \right)}{2 \left( \frac{\partial W_m}{\partial J} \right) + (1 - h_n) \left( \frac{\partial W_m}{\partial J} \right)}
\]

(31)

\[
\rho W_m(G, J) = k (\pi_0 + \sigma G + eJ) + \frac{(r_m + q_m)^2 \left( \frac{\partial W_m}{\partial G} \right)^2}{2 \mu_{B_m}(1 - a_m)} + \frac{(f_m + j_m)^2 \left( \frac{\partial W_m}{\partial J} \right)^2}{2 \mu_{S_m}(1 - h_m)} - \frac{8 \mu_{B_n}(1 - a_n) \left( \frac{\partial W_m}{\partial G} \right) + (1 - a_n)^2 \left( \frac{\partial W_n}{\partial G} \right)}{2 \mu_{B_n}(1 - a_n)^2} + \frac{(f_n + j_n)^2 \left( \frac{\partial W_m}{\partial J} \right) + (1 - h_n)^2 \left( \frac{\partial W_m}{\partial J} \right)}{2 \mu_{S_n}(1 - h_n)^2} - \phi G \frac{\partial W_m}{\partial G} - \theta J \frac{\partial W_m}{\partial J}
\]

(32)

\[
\rho W_n(G, J) = (1 - k) (\pi_0 + \sigma B + eJ) + (r_n + q_n)^2 \left( \frac{\partial W_n}{\partial G} \right) + (1 - a_n) \left( \frac{\partial W_n}{\partial G} \right) + \frac{4 \mu_{B_n}(1 - a_n)^2 \left( \frac{\partial W_n}{\partial J} \right) + (1 - h_n)^2 \left( \frac{\partial W_n}{\partial J} \right)}{4 \mu_{B_n}(1 - a_n)^2} + (r_m + q_m)^2 \left( \frac{\partial W_m}{\partial G} \right) + (f_m + j_m)^2 \left( \frac{\partial W_m}{\partial J} \right) - \sigma G \frac{\partial W_n}{\partial G} - \theta J \frac{\partial W_n}{\partial J}
\]

(33)
Substituting (28), (29), (30) and (31) into (26) and (27), the following can be obtained, (32) and (33), as shown at the bottom of the previous page.

Let the solution of the binary first-order function of $G$ and $J$ be

$$W_M (G, J) = \alpha_3 G + \beta_3 J + \eta_3$$

$$W_N (G, J) = \alpha_4 G + \beta_4 J + \eta_4$$

where $\alpha_3, \alpha_4, \beta_3, \beta_4, \eta_3$ and $\eta_4$ are all constants. Substitute the partial derivatives of $W_M(G, J)$, $W_N(G, J)$, $G$ and $J$ into (32) and (33) to obtain, (36) and (37), as shown at the bottom of the page.

Substituting the values of the above parameters into (28) and (29) reveals the optimal decision of the two enterprises, and substituting them again into (30) and (31) shows the optimal proportion $x_B$ and $x_S$ of leading enterprises sharing costs for following enterprises.

Substituting the results into (1) and (2), we can obtain the track of optimal benefits achieved by investing in new infrastructure and maintaining social network security:

$$G^* = I_3 + (G_0 - I_3)e^{-\delta t}$$

$$J^* = I_4 + (J_0 - I_4)e^{-\delta t}$$

Among them,

$$I_3 = \frac{\sigma k(r_M + q_M)^2}{\phi \mu_{B_M}(1 - a_M)(\rho + \phi)} + \frac{\sigma (r_N + q_N)^2 [2k(1 - k)(1 - a_N)]}{2\phi \mu_{B_N}(1 - a_N)^2(\rho + \delta)}$$

$$I_4 = \frac{\sigma \mu_{S_M}(1 - h_M)(\rho + \theta)}{\beta \mu_{S_N}(1 - h_N)^2(\rho + \theta)} + \frac{\epsilon [2k(1 - h_N)](f_M + j_M)^2}{2\delta \mu_{S_N}(1 - h_N)^2(\rho + \theta)}$$

By substituting each value in (36) and (37) into (34) and (35), the optimal benefit function of leading enterprises and following enterprises can be obtained respectively, and the optimal value of total revenue of digital innovation ecosystem under the master–slave game is, (40), as shown at the bottom of the page.

End of proof.

**E. NON-DOMINANT SYMBIOTIC GAME SCENARIO**

In the case of a non-dominant symbiotic game, leading enterprises and following enterprises do not aim to maximize their own interests but to improve the overall benefit of the
digital ecosystem through mutual cooperation. In this case, the overall objective function can be obtained as follows:

\[
Z = Z_M + Z_N
\]

\[
= \max_{B_i \geq 0, S_i \geq 0} \int_0^{+\infty} e^{-\rho t} \left[ \pi(t) - \frac{\mu_B}{2}(1 - a_M)B_i^2 - \frac{\mu_S}{2}(1 - h_M)S_i^2 \right] dt
\]

Theorem 3: When leading enterprises and following enterprises cooperate in innovation on an equal footing, the optimal decision of both parties is

\[
B'_M = \frac{(r_M + q_M)\sigma}{\mu_B(1 - a_M)(\rho + \phi)},
\]

\[
S'_M = \frac{(j_m + j_M)\epsilon}{\mu_S(1 - h_M)(\rho + \theta)}
\]

\[
B'_N = \frac{(r_N + q_N)\sigma}{\mu_B(1 - a_N)(\rho + \phi)},
\]

\[
S'_N = \frac{(j_n + j_N)\epsilon}{\mu_S(1 - h_N)(\rho + \theta)}
\]

Proof: To obtain the optimal benefit strategy of a non-dominant symbiotic game, the bounded differential function of both benefits is denoted as \(W(G, J)\); for all \(G \geq 0, J \geq 0\), the enterprise’s HJB equation is satisfied:

\[
\rho W(G, J) = \max_{B_i \geq 0, S_i \geq 0} \left( \pi_0 + (\sigma - \phi) \frac{\partial W}{\partial G} + (\epsilon - \theta) \frac{\partial W}{\partial J} \right)
\]

Substituting (45) and (46) into (44), we can obtain

\[
\rho W(G, J) = \pi_0 + (\sigma - \phi) \frac{\partial W}{\partial G} + (\epsilon - \theta) \frac{\partial W}{\partial J}
\]

Let the solution of the binary first-order function of \(G\) and \(J\) be

\[
W(G, J) = \alpha U + \beta T + \eta
\]

where \(\alpha, \beta\) and \(\eta\) are all constants. Substitute the partial derivatives of \(W_M(G, J), W_N(G, J)\) and \(G\) and \(J\) into (47) to obtain (49), as shown at the bottom of the page.

By substituting the above values into (45) and (46), the optimal decision can be obtained, namely, (42) and (43).

By substituting the results into (1) and (2), the trajectory of achieving optimal benefits through investment in new infrastructure and maintenance of social network security can be obtained:

\[
G = I_5 + (G_0 - I_5) e^{-\phi t}
\]

\[
J = I_6 + (J_0 - I_6) e^{-\theta t}
\]

Among them,

\[
I_5 = \frac{\sigma (r_M + q_M)^2}{\phi \mu_B(1 - a_M)(\rho + \phi)} + \frac{\sigma (r_N + q_N)^2}{\phi \mu_B(1 - a_N)(\rho + \phi)}
\]

\[
I_6 = \frac{\epsilon (j_m + j_M)^2}{\theta \mu_S(1 - h_M)(\rho + \theta)} + \frac{\epsilon (f_n + j_N)^2}{\theta \mu_S(1 - h_N)(\rho + \theta)}
\]
accuracy of the inference, the function expression of the

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is randomly set as follows [40], [41], the assignment of relevant parameters in this paper

new infrastructure and maintain social network security under

lowing enterprises have the lowest enthusiasm to invest in
digital innovation ecosystem. Leading enterprises and fol-

conducive to the sustainable and healthy development of a

security. If the profit proportion of leading enterprises is less

enterprise, which encourages it to increase its enthusiasm
does not change.

non-cooperative game.

non-dominant symbiotic game are better than those in Nash

three cases, the following conclusions can be drawn:

F. COMPARATIVE ANALYSIS

By comparing the optimal decisions of both parties under the

cases, the following conclusions can be drawn:

Corollary 1: The optimal returns of leading enterprises and

following enterprises in Stackelberg master–slave game and

non-dominant symbiotic game are better than those in Nash

non-cooperative game.

Corollary 2: In Stackelberg’s master–slave game, the leading

enterprise’s profit proportion is between 1/3 and 1, and it

shares a certain proportion of costs with the following

enterprise, which encourages it to increase its enthusiasm to

invest in new infrastructure and maintain social network

security. If the profit proportion of leading enterprises is less

than or equal 1/3, the enthusiasm of following enterprises
does not change.

Corollary 3: Reasonable investment in new infrastructure

and appropriate maintenance of social network security are

conducive to the sustainable and healthy development of a
digital innovation ecosystem. Leading enterprises and fol-

lowing enterprises have the lowest enthusiasm to invest in

new infrastructure and maintain social network security under

Nash non-cooperative game. Moreover, the benefits obtained

are lower than those obtained in the non-dominant symbiotic

game and Stackelberg master–slave game.

G. THE EXAMPLE ANALYSIS

First, according to parameter values in the literature

[40], [41], the assignment of relevant parameters in this paper

is randomly set as follows:

\[
\begin{align*}
\mu_B &= 0.5, & \mu_N &= 0.3, & \mu_M &= 0.4, \\
\mu_S &= 0.2, & \kappa &= 0.2, & \eta &= 0.2, & \theta &= 0.1, & \sigma &= 3.5, & \epsilon &= 2, & k &= 0.6, & aM &= 0.3, & aN &= 0.3, & h_M &= 0.2, & h_N &= 0.2, & \rho &= 0.1, & \gamma_0 &= 50, & t &= 1, & G_0 &= 10, & J_0 &= 5
\end{align*}
\]

The following can be obtained:

\[
\begin{align*}
B''_M &= 7.2, & B'_M &= 7.2, & B_c &= 12, \\
S''_M &= 5.63, & S'_M &= 5.63, & S''_N &= 9.38, & B''_N &= 5.33, \\
B'_N &= 14.09, & B'_N &= 13.33, & G'' &= 12.02, \\
J''' &= 20.65, & W'' &= 1319.88, & G' &= 14.91, \\
J'' &= 21.96, & W' &= 1633.09, & G &= 17.03, \\
J &= 23.15, & W &= 1555.02
\end{align*}
\]

Therefore, Corollary 1-3 is justified. To further verify the

accuracy of the inference, the function expression of the

special solution of the first-order differential equation can be

obtained as follows:

\[
G'' = 16.13 - 6.13e^{0.11t}, \quad J'' = 26.88 - 6.88e^{0.11t}, \quad \text{total revenue} \quad W'' = 7G + 10J + 1029.24;
\]

\[
G' = 24.9 - 14.9e^{0.12t}, \quad J' = 40.63 - 20.63e^{0.12t}, \quad \text{total revenue} \quad W' = 7G + 10J + 1309.12;
\]

\[
G = 31.33 - 21.33e^{0.15t}, \quad J = 53.13 - 33.13e^{0.15t}, \quad \text{total revenue} \quad W = 7G + 10J + 1204.31.
\]

Comparing the return function of leading enterprises in the

Nash game and Stackelberg master–slave game,

\[
W''_M = 4.2G + 6J + 590.96, \quad W'_M = 4.2G + 6J + 746.87
\]

The details are shown in Fig. 2-7.

![FIGURE 2. Comparison of changes in new infrastructure technology reserve level of enterprises of both sides under the three scenarios.](image)

![FIGURE 3. Comparison of the social achievements of the two parties’ enterprises in maintaining network information security under the three situations.](image)

From the trend in Fig. 2 and Fig. 3, it can be seen that leading enterprises and following enterprises consciously

maintain social network security in the digital innovation

ecosystem. The benefits and social outcomes of investment in

new infrastructure are positively correlated with time, and the

benefits of both are the highest in the case of non-dominant

symbiosis. The Stackelberg master–slave scenario had the

next highest efficiency, and Nash had the lowest efficiency.

The obvious benefit change at the beginning verifies the

conclusion of Corollary 1.

Through analyzing Fig. 4-7, it can be seen that the benefits

of leading enterprises and following enterprises in Stackel-

berg master–slave game are higher than those in Nash
non-cooperative condition. This indicates that the digital innovation ecosystem plays a positive role for enterprises, and with the increase in government subsidy rate, the proportion of revenue obtained by leading enterprises will decrease, but it does not affect the trend of revenue growth. In the early stage of investment in new infrastructure and receiving government subsidies, the overall returns of enterprises in Stackelberg master–slave game are slightly higher than those in non-dominant symbiotic game. With the extension of time, the enterprise gradually increases its maturity, and the overall benefits of both enterprises in the non-dominant symbiotic game will exceed the overall benefits of the Stackelberg master–slave game and always maintain a certain gap.

V. CONCLUSION AND SUGGESTIONS
This paper uses differential game theory based on the perspective of corporate social responsibility, combined with the concept of symbiosis and a win–win scenario of the digital innovation ecosystem, and introduces the maintenance of network security into the factors that affect the overall revenue of enterprises in the system and studies the optimal decision-making behaviors and social outcomes that leading and following enterprises can take. The digital innovation ecosystem can not only improve the digital innovation ability of enterprises but also strengthen the security guarantee of social network. Generally, the digital innovation ecosystem is generated with digital leading enterprises as the core, and its ultimate purpose is to form a non-dominant coexistence and win–win survival mode, but there is inevitable complexity when social responsibility is involved. Therefore, this paper uses HJB to investigate the optimal decision-making of enterprises of both sides and the assistance and guidance of leading enterprises to following enterprises, combined with the government’s subsidies for enterprise digital transformation and maintenance of social network security under three situations of non-cooperative, master–slave and non-dominant symbiotic relationships, and through the comparative analysis and the example verification analysis, the following conclusions and relevant suggestions are provided:

(1) The initiative of leading enterprises to invest in new infrastructure remains unchanged in the Nash non-cooperative game and Stackelberg master–slave game. However, because leading enterprises can bear a certain proportion of costs for the following enterprises and provide assistance by giving full play to their digital advantages, following enterprises are more enthusiastic about investing in new infrastructure and can actively carry out digital innovation research and development. Therefore, the overall returns
of both enterprises in the Stackelberg game are higher than those in the Nash non-cooperative game. In the case of non-dominant symbiotic game, enterprises on both sides have higher enthusiasm to invest in new infrastructure and carry out digital improvement; in the end, the overall returns are better than in the case of the Nash non-cooperative game.

(2) In the digital innovation ecosystem, along with digital innovation, maintaining social network security is also extremely important. The proper undertaking of social responsibility by enterprises is conducive to enhancing the level of social value and success of enterprises, widening the scope of resource acquisition and reducing the cost of enterprise behavior. The government strongly supports enterprises in digital transformation while maintaining social network security and provides certain subsidies, encouraging the development model of enterprises toward a non-dominant symbiotic progressive approach. In the case of a non-dominant game, enterprises on both sides can achieve the highest social results due to maintaining social network security. The Stackelberg master–slave game provided the second greatest benefit, while the benefits provided by the Nash non-cooperative game were the lowest.

(3) Enterprises rely on the digital innovation ecosystem to share resources and cooperate with each other to achieve win–win results. The ultimate goal is to form a non-dominant symbiotic development environment. The improvement of the subsidy rate provided by the government to following enterprises will affect the proportion of the overall benefits obtained by leading enterprises. However, overall, the declining share of subsidies received by leading enterprises will not result in a loss of profits; government behavior has a positive effect on the overall benefits of the digital innovation ecosystem, and the additional benefits created by corporate cooperation are far greater than the internalized benefits. However, digital transformation is not achieved overnight, and a certain time lag needs to be tolerated. The cooperation model needs to be continuously explored and improved so that the overall yield of the non-dominant symbiotic model is lower than that of the master–slave model in the early stage of digital transformation innovation. As the partnership model matures, in the end, the returns of the non-dominant symbiosis will still be higher than those provided by the other two scenarios, which is pareto optimal for realizing the returns.

(4) In terms of management responsibilities, decisions made by leading and following firms will dominate the enterprises’ performance, and managers should further improve the direction and strategy of investment in new infrastructure, make specific problem-oriented decisions, consciously fulfill the responsibility of maintaining social network security, and improve internal personnel’s ability to defend and respond to potential risks. At the same time, the government should standardize relevant laws and regulations, implement targeted subsidy measures, optimize the efficiency of government–enterprise cooperation, and reduce the cost of efforts to maintain network security, which will help ensure the high-quality development of the Chinese digital economy.

VI. RESEARCH LIMITATIONS AND FUTURE DEVELOPMENT DIRECTION

In this paper, differential game theory is used to compare the benefits that can be generated by leading enterprises and following enterprises when they make optimal decisions to invest in new infrastructure and maintain social network security under different circumstances. However, the factors affecting digital innovation ecosystem benefits are extremely complex, and the maintenance of social network security is also complex. There are still some limitations in the present study. For example, the impact of random factors on social digital transformation is not considered, and a specific time point at which the benefits of investment in new infrastructure of both companies in the symbiotic situation exceed those of the Stackelberg master–slave situation has not been identified. In the future, other factors affecting the efficiency of the system can be further explored comprehensively, and the influencing factors of network security can be studied more specifically. At the same time, more participants, such as universities and research institutes, will be introduced to jointly participate in digital innovation and strive to explore better strategies.

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