IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 21 December 2023, accepted 30 January 2024, date of publication 5 February 2024, date of current version 22 February 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3362238

RESEARCH ARTICLE

Research on Government Incentive and Enterprise Data Resource Sharing Strategies in Digital Innovation Ecosystems

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ABSTRACT Enterprise data resource sharing is an effective means to promote enterprise collaboration, help the government make scientific and effective decisions, and facilitate the development of the digital innovation ecosystem. In order to accurately analyze the enterprise data resource sharing strategies of digital platform enterprises, cooperative enterprises, and the government and the impact of government incentives on sharing, taking the digital innovation ecosystem as the background, three decision-making models of Nash non-cooperation, Stackelberg, and collaborative cooperation are constructed by using the differential game method. Their equilibrium results are obtained, analyzed comparatively, and simulated numerically. The conclusions are as follows: 1) Under the three strategy options, the data resource sharing effort level is positively correlated with the data resource sharing capability coefficient, the influence coefficient of effort level on the digital innovation ecosystem, the digital technology level coefficient of digital platform enterprises, and negatively correlated with the cost coefficient of data resource sharing and the elimination rate of shared data resources. 2) Government incentives for data resource sharing can raise the data resource sharing effort level by digital platform enterprises and cooperative enterprises and enhance the optimal benefits for all three parties and the system. 3) In the collaborative game, the optimal benefits of the three parties and the system are maximized, and a reasonable benefit distribution coefficient is determined to achieve Pareto optimality. Finally, some suggestions and strategies are provided to promote enterprise data resource sharing and government incentives.

INDEX TERMS Data resource sharing, differential game, digital innovation ecosystem, digital platform enterprise, government incentive.

I. INTRODUCTION

With the continuous advancement of the new technological revolution, digital as a new production factor is involved in innovation activities and promotes the development of innovation theory [1], [2]. Digitalization promotes the change of production factors, reshapes cooperation and sharing between innovation subjects, and gives rise to the digital innovation ecosystem. The digital innovation ecosystem is a complex economic system that relies on digital technology, introduces data resources, enhances cooperation and information sharing among subjects, promotes the association and reorganization of factors, and thus improves system efficiency and innovation [3]. Data resources refer to data that has value through processing. Its value is not determined by itself but by demand, in the future tense, and subject to judgment. The same data in different scenarios will also have different values. Data resources are built based on digital technology, breaking through time and space barriers, realizing resource complementarity, sharing across levels, and generating new

The associate editor coordinating the review of this manuscript and approving it for publication was Ilaria De Munari.

value creation paths and ecological relationships [4], so data resources have become a competitive resource for enterprises.

Enterprises are direct participants in socio-economic activities and have massive data resources with significant economic and social governance values [5]. Such as Walmart, Amazon, Alibaba, and other enterprises, understand users' consumption habits and demand tendencies through users' purchase histories, browsing behaviors, and other data resources, and provide users with personalized recommendation services. Identify product sales trends and forecast future demand trends through historical sales data resources. Through users' feedback and evaluation of products, understand the advantages and disadvantages of products and market feedback, and provide the basis for product improvement and optimization. Data resource sharing can realize the value of data resources and drive value creation in digital innovation ecosystems. Enterprise data resource sharing is the process by which an enterprise makes data acquired or collected in its production operations available to other enterprises for use, free of charge or for a fee [6]. Enterprise data resource sharing helps enterprises break down data silos, collaborate efficiently, develop with high quality, fulfill social responsibilities better, enhance corporate image, and may also obtain material incentives from the government [7]. And it helps the government make more scientific and effective decisions, improve the level of social governance and public services, and promote the development of the digital economy [5]. However, data resources are characterized by non-competitiveness, replicability, and non-exclusivity [8]. Enterprise data resource sharing faces problems of risk, trust, and security, resulting in low circulation of data resources among enterprises. Enterprises holding data are worried that data sharing will impair their competitiveness and that data privacy will be disclosed. Enterprises' enthusiasm for data resource sharing is not high, data value has not been fully released, and data monopolies may also occur [9].

Therefore, local governments need to ensure that data ethical issues such as data privacy, data security, and digital accessibility that may be encountered during enterprise data resource sharing are supervised [10]. National governments need to adopt incentive strategies to strengthen enterprise data resource sharing behaviors, address market failures, and achieve win-win goals for enterprise and society. Basis on this, this paper takes the digital innovation ecosystem as the background, constructs a differential game model with the participation of the digital platform enterprise holding a large amount of data resources, other cooperative enterprises participating in data resource sharing, and the government adopting incentive strategies, and takes the digital technology level of digital platform enterprises into account. The optimal returns under different cooperation models are mainly investigated. Firstly, the optimal strategies, optimal benefits, and overall optimal benefits of the digital innovation ecosystem in each of the three scenarios of the Nash non-cooperative, Stackelberg, and collaborative game models are analyzed and calculated. Secondly, the optimal strategy of the three parties is obtained, and the benefit distribution mechanism of the three parties is discussed. The impact of the digital technology level of digital platform enterprises on ecosystem benefits is analyzed, and the key influencing factors of enterprise data resource sharing behavior and its mechanisms are explored. Finally, the optimal benefits under the three cooperation modes are compared, and numerical simulations are conducted for essential parameters to provide theoretical guidance and decision support for promoting the development of enterprise data resource sharing under government incentive strategies in digital innovation ecosystems.

The innovations of this paper mainly include: (1) This paper explores the strategy analysis of enterprise data resource sharing from the micro perspective of government incentives in the digital innovation ecosystem, which helps the government choose more effective incentive strategies to promote the development of enterprise data resource sharing. (2) This paper constructs a differential game model with the participation of digital platform enterprises, cooperative enterprises, and the government and takes the time factor into account to analyze the dynamic revenue allocation mechanism of the three parties under time synchronization to ensure the stability of revenue allocation. (3) This paper takes the digital platform enterprise as both the sharing party and the platform party providing the place and takes the level of digital technology into consideration, which enriches the theoretical foundation of the digital platform field and facilitates the digital platform enterprise to play a better role in sharing.

II. THEORETICAL BASIS AND RESEARCH REVIEW

A. RELATED RESEARCH ON A DIGITAL PLATFORM ENTERPRISE

In the era of the digital economy, digital platform enterprises refer to enterprises that utilize digital technology to build digital platforms, provide products and services in this way, and connect two or more parties through digital platforms [11]. Alstyne et al. found that digital platform businesses have exploded across industries due to digital technologies breaking capacity constraints and physical limitations [12]. Evans and Gawer stated that the value of digital platform enterprises is co-created by the platform participants, creating network effects and growing with the number of users [13]. He and Sun proposed that digital platform enterprises have the construction responsibility of guaranteeing platform governance and maintaining platform upgrades, the governance responsibility of governing the behavior of platform participants, and the social response responsibility of responding to the government's expectations and the public's demands [14]. Qiu proposed that the governance logic of digital platform enterprises is to make full use of their large-scale characteristics and advantages, actively explore the regulation of data ownership, and promote equity in the distribution of digital dividends, thus promoting social equity [15]. Therefore, the digital platform enterprise in this paper is both a sharing party that provides data resources and a platform party that provides a sharing place. It plays a crucial role in data resource sharing by building a digital platform to connect cooperative enterprises to participate in data resource sharing.

The digital platform is constructed by digital platform enterprises and is the signature feature of digital platform enterprises [11]. The digital platform is a platform that takes digital technology as its core, utilizes digital technology to integrate diversified data resources, and makes the subjects within the digital platform highly interconnected to provide resource sharing services for each subject [16]. Elia et al. pointed out that digital platform development depends on digital technologies [17]. Koskinen et al. argued that the essential characteristics of digital platforms are mediated by digital technologies, support interactive communication among different user groups, and allow user groups to do specific things [18]. Zhou and Cheng, suggested that digital platforms enable efficient cross-border collaboration between innovation subjects and have become a resource-sharing vehicle across organizational boundaries [19]. The digital platform is an essential force in developing the digital economy, as it enables all subjects to interact and share, provides a place to share data resources, and fundamentally changes how resources are shared through digital technology.

B. RELATED RESEARCH ON THE DIGITAL INNOVATION ECOSYSTEM

With the wide application of digital technology, the intrinsic nature of innovation has largely changed, and digital innovation has become an emerging mode of innovation, subverting the traditional innovation theory [20]. Digital innovation refers to the process of innovation using digital technologies. It can be used to describe both parts of the outcome of an innovation and the whole of the innovation [21]. Abrell et al. stated that digital innovation is the use of digital technology to accelerate the production of products and delivery of services and improve the innovation process's performance [22]. The innovation ecosystem is considered to be a complex system formed by multiple subjects characterized by symbiotic coupling and competing relationships [23]. Scholars' research on innovation ecosystems mainly includes conceptual connotation [24], evolutionary mechanisms [25], governance mechanisms [26], and regional innovation ecology [27].

The digital innovation ecosystem is the combination of digital innovation and the innovation ecosystem [28], which refers to an ecological organization system in which innovation subjects complement and share resources across levels through digital technology and achieve value co-creation through competitive relationships [29], [30]. Both the general characteristics of innovation ecosystems and unique characteristics related to digital technology are presented, such as the more significant heterogeneity of innovation subjects, the more complex flow of resources, and the more open sharing of data [31], so the digital innovation ecosystem is a dynamic process of continuous iterative evolution [32]. Suseno et al. considered digital innovation ecosystems as complex systems that create new products and value through digital technologies [33]. Adner stated that digital technologies, digital resources, and digital infrastructure in digital innovation ecosystems have become key production factors for innovation and have reshaped the logic of value co-creation [34]. Wei and Zhao pointed out the governance dilemma of digital innovation ecosystems and proposed new governance mechanisms and critical scientific governance issues [29].

C. RELATED RESEARCH ON DATA RESOURCE SHARING

Under the digital transformation, digital technologies are widely used in all aspects, and data resources are being created. As a new production factor influencing innovation activities, data resources are the key driving force for the development of digital innovation ecosystems, creating disruptive changes to the value output of digital innovation ecosystems and driving the continuous evolution of digital innovation ecosystems, which has attracted extensive attention from more and more scholars [4]. Svahn et al. argued that data resources disrupt how value is captured and created by subjects in the process of product innovation in digital innovation ecosystems, helping them to better cope with changes in the external environment [35]. Qi and Liu proposed that data resource elements have low competitiveness and high generalizability, which breaks the limit of reserves, eases the pressure of inter-subjective resource competition, and improves the efficiency of subjective production factor allocation [36]. Unlike traditional resources, data resources are shared as a way to fully realize their value [37]. But there are corresponding problems at the same time, and the related data ethics problems are also very different under different data sharing scenarios [38]. Xing pointed out that the protection of personal information during the current government data sharing in China is insufficient, and a government data sharing law should be formulated [39]. Su and Ji pointed out that current medical data sharing has problems such as difficulty guaranteeing privacy and security risks and insufficient motivation, and that a synergistic mechanism of medical data sharing can be constructed to enhance the open governance of healthy medical data [40]. An enterprise's data resources hold a great deal of information related to the operation of individual users and society. Enterprise data resource sharing can promote the development of the digital economy, promote enterprise cooperation and collaborative development, help the government make more scientific and effective decisions, and then improve social governance and public services [5]. Wang and Wei suggested that data resource sharing can increase the probability and scale of collaborative innovation inputs among firms [41]. Du et al. pointed out that the dynamic nature of data resources and firm relationships influence firms' willingness to share data resources [42]. Wei et al. found that data heterogeneity and trust level play a key role in enterprise data resource sharing, and policy tools such as government subsidies have a guiding role [43].

To avoid monopolization of enterprise data resources, Chen and Ma proposed to construct a platform enterprise data resource sharing system from three aspects: mandatory sharing mechanisms, official guidelines, and fair safeguards for platform enterprise data resource sharing [44].

D. THE SHORTCOMINGS AND INISGHTS OF EXISTING RESEARCH

In summary, the research on digital platform enterprises focuses on the development process, value creation, social responsibility, and regulatory governance, which provides theoretical and directional guidance for subsequent research. The research on digital innovation ecosystems mostly focuses on conceptual structure, system evolution, and governance mechanisms, which provides a solid theoretical basis for subsequent research. However, the research on data resource sharing mainly focuses on scientific, technological, governmental, medical, and other data resources, focusing on facing dilemmas and sharing programs. And most of them are from macro and strategic perspectives, rarely from the micro perspective of government incentive strategy to study the differential game analysis of the tripartite subjects about enterprise data resource sharing strategies.

This paper constructs a differential game model involving digital platform enterprises, cooperative enterprises, and the government under the background of the digital innovation ecosystem and studies the strategy choice of enterprise data resource sharing under the government incentive so as to make up for the deficiency of existing literature. It helps to enrich the field of digital platforms and the theory of data resource sharing, provides decision support for the benign development of digital innovation ecosystems and government incentive strategies to promote enterprise data resource sharing, and provides a theoretical basis for the differential game about enterprise data resource sharing in digital innovation ecosystems. Therefore, the research in this paper is of great theoretical and practical significance.

III. PROBLEM DESCRIPTION AND MODEL ASSUMPTION

A. PROBLEM DESCRIPTION

This paper examines the sharing of enterprise data resources among digital platform enterprises, cooperative enterprises, and governments in a digital innovation ecosystem. As shown in Fig. 1, in this system, digital platform enterprises build digital platforms through digital technology to provide places for data resource sharing and provide data resources and access to information through the digital platform. Cooperative enterprises provide data resources to the digital platform and also obtain the required information from the platform. Through the sharing of enterprise data resources, further enhance the information development level, improve the economic efficiency of enterprises, drive the development of the digital economy, and promote the development and change of the industry. Through the incentive strategies, the government has motivated digital platform enterprises and cooperative enterprises to share data resources and, at the same time, obtain information from digital platforms, and the information development level has been enhanced, which helps to make more scientific and rational decisions and thus improves the level of social governance and public services.

TABLE 1. Parameter symbols and meanings.

symbols	meanings
P	Digital platform enterprise.
E	Cooperative enterprise.
G	Government.
$A_i(t)$	Data resource sharing effort level, $i=P,E,G$.
k_i	Cost coefficient of data resource sharing, $i=P,E,G$.
f_P	Digital technology level coefficient of digital platform enterprises.
$C_i(t)$	Data resource sharing cost, $i=P,E,G$.
$I(t)$	Information development level at moment t.
λ_i	Data resource sharing capability coefficient, $i=P,E,G$.
δ	Elimination rate of shared data resources.
$\pi(t)$	Total revenue of the digital innovation ecosystem at moment t.
η_i	Influence coefficient of effort level on the digital innovation ecosystem, $i=P,E,G$.
ω	The influence coefficient of shared data resources on the digital innovation ecosystem.
α	Revenue distribution coefficient of digital platform enterprises.
β	Revenue distribution coefficient of cooperative enterprises.
$1-\alpha-\beta$	Revenue distribution coefficient of the government.
σ	The incentive coefficient of the government to digital platform enterprises.
θ	The incentive coefficient of the government to cooperative enterprises.
μ	Discount rate at any time.

B. SYMBOL DESCRIPTION

In the context of digital innovation ecosystems, three decision-making models, namely Nash non-cooperative, Stackelberg, and collaborative game, are utilized to explore the differences in the strategies of digital platform enterprises, cooperative enterprises, and the government when they engage in enterprise data resource sharing. The symbols and meanings of the parameters involved in the above three models are shown in Tab. 1.

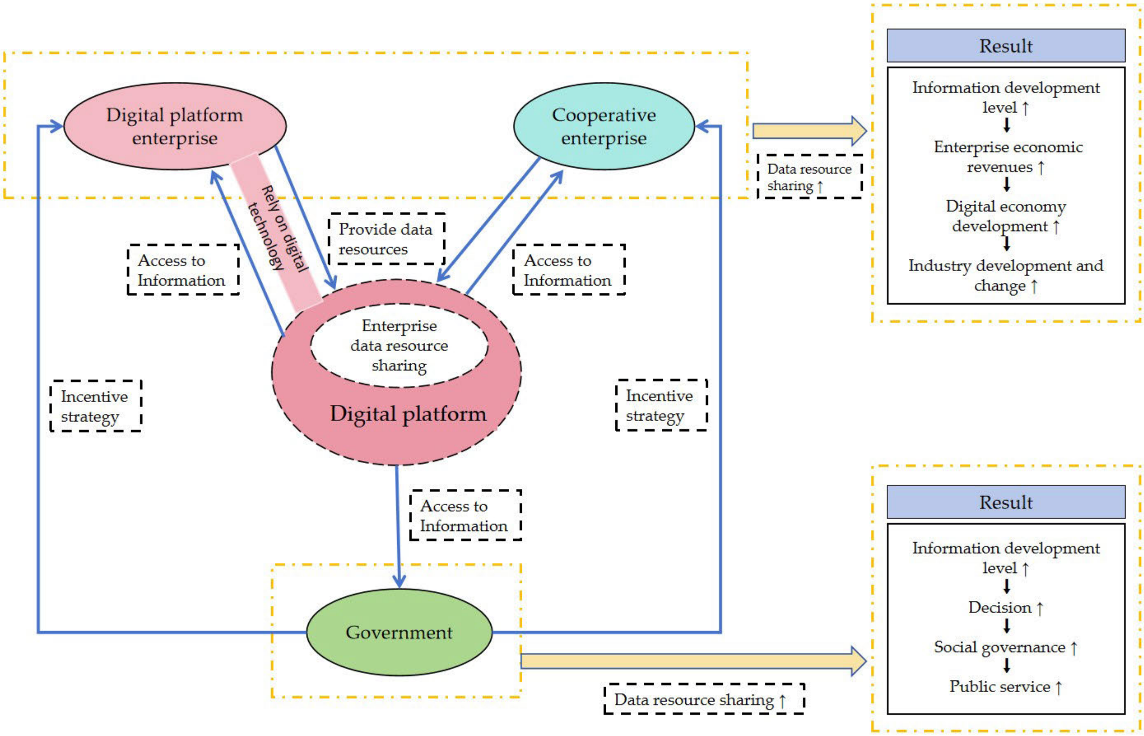


FIGURE 1. The logic for enterprise data resource sharing in digital innovation ecosystems.

C. BASIC ASSUMPTION

This paper considers that the subjects of enterprise data resource sharing in the digital innovation ecosystem are composed of digital platform enterprises, cooperative enterprises, and the government, all of which are rational subjects, and the basic assumptions are as follows:

Hypothesis 1: The data resource sharing cost of digital platform enterprises, cooperative enterprises, and government is related to the data resource sharing effort level, and the data resource sharing cost is a convex function of the data resource sharing effort level, i.e., the data resource sharing cost increases with the increase of the data resource sharing effort level, so the expression of the tripartite cost function is:

$$C_P(t) = \left(\frac{k_P}{2} + \frac{1}{f_p}\right) A_P^2(t)$$
$$C_E(t) = \frac{k_E}{2} A_E^2(t)$$
$$C_G(t) = \frac{k_G}{2} A_G^2(t) \tag{1}$$

Hypothesis 2: As data resource sharing is a dynamic and changing process, it requires participants to make efforts to share data resources and continuously improve the information development level in the digital innovation ecosystem. Therefore, the stochastic differential equation is utilized to represent the change in the information development level in the digital innovation ecosystem over time as follows:

$$I'(t) = \frac{dI(t)}{dt} = \lambda_P A_P(t) + \lambda_E A_E(t) + \lambda_G A_G(t) - \delta I(t) \tag{2}$$

Among them is the initial state of information development in the digital innovation ecosystem $I(0) = I_0 \geq 0$.

Hypothesis 3: Data resources shared by enterprises, as a new production factor, can enhance the information development level, improve the economic efficiency of enterprises, promote the development and change of industries, and enhance the level of government public services and social governance, bringing significant benefits to society. Assume that the total revenue of the digital innovation ecosystem at moment t is:

$$\pi(t) = \pi_0 + \eta_P A_P(t) + \eta_E A_E(t) + \eta_G A_G(t) + \omega I(t) \tag{3}$$

where $\pi_0 > 0$ denotes the initial state of the digital innovation ecosystem.

Hypothesis 4: The total revenues of the digital innovation ecosystem are distributed among the three parties in the proportion agreed upon by them, with the distribution coefficients α, β, and $1 - \alpha - \beta$ being constants between (0,1) and based on the level of importance and contribution of the three parties in generating the benefits from the sharing of data resources. To build an open sharing ecosystem, the government will incentivize digital platform enterprises and cooperative enterprises to participate in digital resource sharing with incentive coefficients $\sigma, \theta \in [0, 1]$. Assuming that all three parties are rational decision-makers with complete information, they aim to find the data resource-sharing strategy that maximizes their benefits continuously.

IV. MODEL CONSTRUCTION AND ANALYSIS

In order to better analyze the equilibrium state of the data resource sharing effort levels of digital platform enterprises, cooperative enterprises, and the government and to verify the effectiveness of the incentive mechanism, this paper examines the three scenarios of the Nash non-cooperative game (labeled with N for convenience of differentiation), the Stackelberg game (labeled with S), and the collaborative game (labeled with C), respectively, under which the objectives of the digital platform enterprises, the cooperative enterprises, and the government are all to seek for their respective data resource sharing strategies with the most significant gains in a continuous period. The three-party objective functions are as follows:

The objective function of the digital platform enterprise is:

$$J_P = \max_{A_P(t)\geq 0} \int_0^\infty e^{-\mu t} [\alpha \pi(t) - (1-\sigma(t)) \left(\frac{k_P}{2} + \frac{1}{f_P}\right) A_P^2(t)] dt \tag{4}$$

The objective function of the cooperative enterprise is:

$$J_E = \max_{A_E(t)\geq 0} \int_0^\infty e^{-\mu t} [\beta \pi(t) - (1-\theta(t)) \frac{k_E}{2} A_E^2(t)] dt \tag{5}$$

The objective function of the government is:

$$J_G = \max_{A_G(t)\geq 0} \int_0^\infty e^{-\mu t} [(1-\alpha-\beta)\pi(t) - \frac{k_G}{2} A_G^2(t) - \sigma(t) \left(\frac{k_P}{2} + \frac{1}{f_P}\right) A_P^2(t) - \theta(t) \frac{k_E}{2} A_E^2(t)] dt \tag{6}$$

The control variables in the model are $A_P(t)$ $A_E(t)$ $A_G(t)$ $\theta(t)$ $\gamma(t)$, and the state variable is $I(t)$. The remaining parameters are time-independent constants. For convenience, t will be omitted below. In the following writing $A_P(t)$, $A_E(t)$, $A_G(t)$, $\theta(t)$, $\gamma(t)$ and $I(t)$ are denoted as A_P, A_E, A_G, θ, γ and, I respectively.

A. NASH NON-COOPERATIVE GAME MODEL

In the Nash non-cooperative game scenario, digital platform enterprises, cooperative enterprises, and the government are independent of each other and have equal status. All three parties' decision-making goals are to maximize their interests, and the government will not provide incentives to digital platform enterprises and cooperative enterprises, i.e., $\sigma = 0$ and $\theta = 0$. The three parties make optimal decisions simultaneously and independently, and combining strategies constitutes a Nash equilibrium solution. At this time, the objective functions of digital platform enterprises, cooperative enterprises, and the government are shown in equations (7) to (9):

$$J_P = \max_{A_P\geq 0} \int_0^\infty e^{-\mu t} [\alpha(\pi_0 + \eta_P A_P + \eta_E A_E + \eta_G A_G + \omega I) - \left(\frac{k_P}{2} + \frac{1}{f_P}\right) A_P^2] dt \tag{7}$$

$$J_E = \max_{A_E\geq 0} \int_0^\infty e^{-\mu t} [\beta (\pi_0 + \eta_P A_P + \eta_E A_E + \eta_G A_G + \omega I) - \frac{k_E}{2} A_E^2] dt \tag{8}$$

$$J_G = \max_{A_G\geq 0} \int_0^\infty e^{-\mu t} [(1-\alpha-\beta)(\pi_0 + \eta_P A_P + \eta_E A_E + \eta_G A_G + \omega I) - \frac{k_G}{2} A_G^2] dt \tag{9}$$

Assume that there exist continuously differentiable and bounded revenue functions $V_P(I)$, $V_E(I)$, and $V_G(I)$ for digital platform enterprises, cooperative enterprises, and the government, all of which satisfy the following Hamilton-Jacobi-Bellman (HJB) equation when $I \geq 0$:

$$\mu V_P(I) = \max_{A_P\geq 0} [\alpha (\pi_0 + \eta_P A_P + \eta_E A_E + \eta_G A_G + \omega I) - \left(\frac{k_P}{2} + \frac{1}{f_P}\right) A_P^2 + V_P'(I)(\lambda_P A_P + \lambda_E A_E + \lambda_G A_G - \delta I)] \tag{10}$$

$$\mu V_E(I) = \max_{A_E\geq 0} [\beta (\pi_0 + \eta_P A_P + \eta_E A_E + \eta_G A_G + \omega I) - \frac{k_E}{2} A_E^2 + V_E'(I)(\lambda_P A_P + \lambda_E A_E + \lambda_G A_G - \delta I)] \tag{11}$$

$$\mu V_G(I) = \max_{A_G\geq 0} [(1-\alpha-\beta)(\pi_0 + \eta_P A_P + \eta_E A_E + \eta_G A_G + \omega I) - \frac{k_G}{2} A_G^2 + V_G'(I)(\lambda_P A_P + \lambda_E A_E + \lambda_G A_G - \delta I)] \tag{12}$$

Calculate the first order partial derivative of A_P, A_E and A_G on the right side of (10)-(12), and set them equal to zero. The solution is:

$$A_P = \frac{(\alpha\eta_P + \lambda_P V_P'(I)) f_P}{k_P f_P + 2}$$
$$A_E = \frac{\beta\eta_E + \lambda_E V_E'(I)}{k_E}$$
$$A_G = \frac{(1-\alpha-\beta)\eta_G + \lambda_G V_G'(I)}{k_G} \tag{13}$$

Substitute (13) into (10)-(12), and simplify:

$$\mu V_P(I) = \left[\alpha\omega - \delta V_P'(I)\right] I + \alpha\pi_0 + \frac{f_P \left[\alpha\eta_P + \lambda_P V_P'(I)\right]^2}{2(k_P f_P + 2)} + \frac{\left[\alpha\eta_E + \lambda_E V_P'(I)\right]\left[\beta\eta_E + \lambda_E V_E'(I)\right]}{k_E} + \frac{\left[\alpha\eta_G + \lambda_G V_P'(I)\right]\left[(1-\alpha-\beta)\eta_G + \lambda_G V_G'(I)\right]}{k_G} \tag{14}$$

$$\mu V_E(I) = \left[\beta\omega - \delta V_E'(I)\right] I + \beta\pi_0 + \frac{f_P\left[\alpha\eta_P + \lambda_P V_P'(I)\right]\left[\beta\eta_P + \lambda_P V_E'(I)\right]}{k_P f_P + 2} + \frac{\left[\beta\eta_E + \lambda_E V_E'(I)\right]^2}{2k_E} + \frac{\left[\beta\eta_G + \lambda_G V_E'(I)\right]\left[(1-\alpha-\beta)\eta_G + \lambda_G V_G'(I)\right]}{k_G} \tag{15}$$

$$\mu V_G(I) = \left[(1-\alpha-\beta)\omega - \delta V_G'(I)\right] I + (1-\alpha-\beta)\pi_0 + \frac{f_P\left[\alpha\eta_P+\lambda_P V_P'(I)\right]\left[(1-\alpha-\beta)\eta_P+\lambda_P V_G'(I)\right]}{k_P f_P + 2} + \frac{\left[\beta\eta_E + \lambda_E V_E'(I)\right]\left[(1-\alpha-\beta)\eta_E + \lambda_E V_G'(I)\right]}{k_E} + \frac{\left[(1-\alpha-\beta)\eta_G + \lambda_G V_G'(I)\right]^2}{2k_G} \tag{16}$$

As can be seen from (14)-(16), the unary function with I as the independent variable is the solution of the HJB equation:

$$\begin{aligned} V_P(I) &= a_1 I + b_1 \\ V_E(I) &= a_2 I + b_2 \\ V_G(I) &= a_3 I + b_3 \end{aligned} \tag{17}$$

where $a_1, a_2, a_3, b_1, b_2, b_3$ are constants to be solved, which can be obtained by (17):

$$\begin{aligned} V_P'(I) &= \frac{dV_P(I)}{dI} = a_1 \\ V_E'(I) &= \frac{dV_E(I)}{dI} = a_2 \\ V_G'(I) &= \frac{dV_G(I)}{dI} = a_3 \end{aligned} \tag{18}$$

Substitute (17), (18) into (14)-(16) and organize:

$$\mu\left(a_1 I + b_1\right) = \left(\alpha\omega - \delta a_1\right) I + \alpha\pi_0 + \frac{f_P\left(\alpha\eta_P + \lambda_P a_1\right)^2}{2(k_P f_P + 2)} + \frac{\left(\alpha\eta_E + \lambda_E a_1\right)\left(\beta\eta_E + \lambda_E a_2\right)}{k_E} + \frac{\left(\alpha\eta_G + \lambda_G a_1\right)\left[(1-\alpha-\beta)\eta_G + \lambda_G a_3\right]}{k_G} \tag{19}$$

$$\mu\left(a_2 I + b_2\right) = \left(\beta\omega - \delta a_2\right) I + \beta\pi_0 + \frac{f_P\left(\alpha\eta_P + \lambda_P a_1\right)\left(\beta\eta_P + \lambda_P a_2\right)}{k_P f_P + 2} + \frac{\left(\beta\eta_E + \lambda_E a_2\right)^2}{2k_E} + \frac{\left(\beta\eta_G + \lambda_G a_2\right)\left[(1-\alpha-\beta)\eta_G + \lambda_G a_3\right]}{k_G} \tag{20}$$

$$\mu\left(a_3 I + b_3\right) = \left[(1-\alpha-\beta)\omega - \delta a_3\right] I + (1-\alpha-\beta)\pi_0 + \frac{f_P\left(\alpha\eta_P + \lambda_P a_1\right)\left[(1-\alpha-\beta)\eta_P + \lambda_P a_3\right]}{k_P f_P + 2} + \frac{\left(\beta\eta_E + \lambda_E a_2\right)\left[(1-\alpha-\beta)\eta_E + \lambda_E a_3\right]}{k_E} + \frac{\left[(1-\alpha-\beta)\eta_G + \lambda_G a_3\right]^2}{2k_G} \tag{21}$$

According to the previous assumptions, (19)-(21) are satisfied for all $I \geq 0$, and thus the parameter values of a_1, a_2, a_3, b_1, b_2, b_3 can be obtained respectively:

$$\begin{aligned} a_1 &= \frac{\alpha\omega}{\mu+\delta} \\ a_2 &= \frac{\beta\omega}{\mu+\delta} \\ a_3 &= \frac{(1-\alpha-\beta)\omega}{\mu+\delta} \\ b_1 &= \frac{\alpha\pi_0}{\mu} + \frac{\alpha^2 f_P\left[\eta_P(\mu+\delta) + \lambda_P\omega\right]^2}{2\mu\left(k_P f_P + 2\right)(\mu+\delta)^2} + \frac{\alpha\beta\left[\eta_E(\mu+\delta) + \lambda_E\omega\right]^2}{\mu k_E(\mu+\delta)^2} + \frac{\alpha(1-\alpha-\beta)\left[\eta_G(\mu+\delta) + \lambda_G\omega\right]^2}{\mu k_G(\mu+\delta)^2} \\ b_2 &= \frac{\beta\pi_0}{\mu} + \frac{\alpha\beta f_P\left[\eta_P(\mu+\delta) + \lambda_P\omega\right]^2}{\mu\left(k_P f_P + 2\right)(\mu+\delta)^2} + \frac{\beta^2\left[\eta_E(\mu+\delta) + \lambda_E\omega\right]^2}{2\mu k_E(\mu+\delta)^2} + \frac{\beta(1-\alpha-\beta)\left[\eta_G(\mu+\delta) + \lambda_G\omega\right]^2}{\mu k_G(\mu+\delta)^2} \\ b_3 &= \frac{(1-\alpha-\beta)\pi_0}{\mu} + \frac{\alpha(1-\alpha-\beta)f_P\left[\eta_P(\mu+\delta) + \lambda_P\omega\right]^2}{\mu\left(k_P f_P + 2\right)(\mu+\delta)^2} + \frac{\beta(1-\alpha-\beta)\left[\eta_E(\mu+\delta) + \lambda_E\omega\right]^2}{\mu k_E(\mu+\delta)^2} + \frac{(1-\alpha-\beta)^2\left[\eta_G(\mu+\delta) + \lambda_G\omega\right]^2}{2\mu k_G(\mu+\delta)^2} \end{aligned} \tag{22}$$

Substitute a_1, a_2, a_3 into (13), the optimal data resource sharing effort levels of digital platform enterprises, cooperative enterprises, and the government in the Nash non-cooperative game scenario, respectively:

$$A_{P_1}^* = \frac{\alpha f_P\left[\eta_P(\mu+\delta) + \lambda_P\omega\right]}{\left(k_P f_P + 2\right)(\mu+\delta)} \tag{23}$$

$$A_{E_1}^* = \frac{\beta\left[\eta_E(\mu+\delta) + \lambda_E\omega\right]}{k_E(\mu+\delta)} \tag{24}$$

$$A_{G_1}^* = \frac{(1-\alpha-\beta)\left[\eta_G(\mu+\delta) + \lambda_G\omega\right]}{k_G(\mu+\delta)} \tag{25}$$

Substituting the values in (22) into (17), the optimal revenue functions of digital platform enterprises, cooperative enterprises, and the government in the Nash non-cooperative game scenario are obtained, respectively:

$$V_{P_1}(I)^* = \frac{\alpha\omega}{\mu+\delta} I + \frac{\alpha\pi_0}{\mu} + \frac{\alpha^2 f_P\left[\eta_P(\mu+\delta) + \lambda_P\omega\right]^2}{2\mu\left(k_P f_P + 2\right)(\mu+\delta)^2} + \frac{\alpha\beta\left[\eta_E(\mu+\delta) + \lambda_E\omega\right]^2}{\mu k_E(\mu+\delta)^2} + \frac{\alpha(1-\alpha-\beta)\left[\eta_G(\mu+\delta) + \lambda_G\omega\right]^2}{\mu k_G(\mu+\delta)^2} \tag{26}$$

$$V_{E_1}(I)^* = \frac{\beta\omega}{\mu+\delta}I + \frac{\beta\pi_0}{\mu} + \frac{\alpha\beta f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{\beta^2\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{2\mu k_E(\mu+\delta)^2} + \frac{\beta(1-\alpha-\beta)\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{\mu k_G(\mu+\delta)^2} \tag{27}$$

$$V_{G_1}(I)^* = \frac{(1-\alpha-\beta)\omega}{\mu+\delta}I + \frac{(1-\alpha-\beta)\pi_0}{\mu} + \frac{\alpha(1-\alpha-\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{\beta(1-\alpha-\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{\mu k_E(\mu+\delta)^2} + \frac{(1-\alpha-\beta)^2\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{2\mu k_G(\mu+\delta)^2} \tag{28}$$

Thus, the optimal data resource sharing revenue for the digital innovation ecosystem under this model can be obtained as follows:

$$V_1(I)^* = \frac{\omega I}{\mu+\delta} + \frac{\pi_0}{\mu} + \frac{\alpha(2-\alpha)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{2\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{\beta(2-\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{2\mu k_E(\mu+\delta)^2} + \frac{\left[1-(\alpha+\beta)^2\right]\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{2\mu k_G(\mu+\delta)^2} \tag{29}$$

B. STACKELBERG GAME MODEL

In the Stackelberg game scenario, the government acts as the dominant player in the digital innovation ecosystem, and digital platform enterprises and cooperative enterprises are the followers, for which the government adopts certain incentive strategies to motivate data resource sharing. The government first determines the incentive coefficients for digital platform enterprises and cooperative enterprises to share data resources. After seeing the government's decision, digital platform enterprises and cooperative enterprises will make corresponding strategies to maximize their interests. Rational government can predict digital platform enterprises and cooperative enterprises' follow-through before making final decisions. At this point, the objective functions of the digital platform enterprises, cooperative enterprises, and the government are:

$$J_P = \max_{A_P(t)\geq 0}\int_0^\infty e^{-\mu t} \times \left[\alpha\pi(t) - (1-\sigma(t))\left(\frac{k_P}{2}+\frac{1}{f_P}\right)A_P^2(t)\right]dt \tag{30}$$

$$J_E = \max_{A_E(t)\geq 0}\int_0^\infty e^{-\mu t}\left[\beta\pi(t) - (1-\theta(t))\frac{k_E}{2}A_E^2(t)\right]dt \tag{31}$$

$$J_G = \max_{A_G(t)\geq 0}\int_0^\infty e^{-\mu t}\left[(1-\alpha-\beta)\pi(t) - \frac{k_G}{2}A_G^2(t) - \sigma(t)\left(\frac{k_P}{2}+\frac{1}{f_P}\right)A_P^2(t) - \theta(t)\frac{k_E}{2}A_E^2(t)\right]dt \tag{32}$$

Assume that there exist continuously differentiable and bounded revenue functions $V_P(I)$, $V_E(I)$, and $V_G(I)$ for digital platform enterprises, cooperative enterprises, and the government that satisfy the HJB equation for all $I \geq 0$. Adopting the inverse induction method, the optimal decision problems of digital platform enterprises and cooperative enterprises are first solved, which can be obtained:

$$\mu V_P(I) = \max_{A_P\geq 0}\left[\alpha(\pi_0+\eta_PA_P+\eta_EA_E+\eta_GA_G+\omega I) - (1-\sigma)\left(\frac{k_P}{2}+\frac{1}{f_P}\right)A_P^2 + V_P'(I)(\lambda_PA_P+\lambda_EA_E+\lambda_GA_G-\delta I)\right] \tag{33}$$

$$\mu V_E(I) = \max_{A_E\geq 0}\left[\beta(\pi_0+\eta_PA_P+\eta_EA_E+\eta_GA_G+\omega I) - (1-\theta)\frac{k_E}{2}A_E^2 + V_E'(I)(\lambda_PA_P+\lambda_EA_E+\lambda_GA_G-\delta I)\right] \tag{34}$$

Calculate the first order partial derivative of A_P, A_E on the right side of (33)-(34) and set them equal to zero. The solution is:

$$A_P = \frac{\left[\alpha\eta_P+\lambda_PV_P'(I)\right]f_P}{(1-\sigma)(k_Pf_P+2)} \tag{35}$$

$$A_E = \frac{\beta\eta_E+\lambda_EV_E'(I)}{(1-\theta)k_E} \tag{36}$$

As a rational decision maker, the government can predict the optimal strategy choices of digital platform enterprises and cooperative enterprises in advance. The government will decide the optimal strategy and incentive ratio based on the response functions (33) and (34) of the digital platform enterprises and cooperative enterprises, and its HJB equation can be expressed as follows:

$$\mu V_G(I) = \max_{A_G\geq 0}\left[(1-\alpha-\beta)(\pi_0+\eta_PA_P+\eta_EA_E+\eta_GA_G+\omega I) - \frac{k_G}{2}A_G^2 - \sigma\left(\frac{k_P}{2}+\frac{1}{f_P}\right)A_P^2 - \theta\frac{k_E}{2}A_E^2 + V_G'(I)(\lambda_PA_P+\lambda_EA_E+\lambda_GA_G-\delta I)\right] \tag{37}$$

Calculate the first order partial derivative of A_G on the right side of (37) and set it equal to zero. The solution is:

$$A_G = \frac{(1-\alpha-\beta)\eta_G+\lambda_GV_G'(I)}{k_G} \tag{38}$$

Substitute (35), (36) into (37) and calculate the first order partial derivatives of σ, θ on the right side of (37) and setting them equal to zero. The solution is:

$$\sigma = \frac{(2-3\alpha-2\beta)\eta_P+\lambda_P\left[2V_G'(I)-V_P'(I)\right]}{(2-\alpha-2\beta)\eta_P+\lambda_P\left[2V_G'(I)+V_P'(I)\right]} \tag{39}$$

$$\theta = \frac{(2-2\alpha-3\beta)\eta_E+\lambda_E\left[2V_G'(I)-V_E'(I)\right]}{(2-2\alpha-\beta)\eta_E+\lambda_E\left[2V_G'(I)+V_E'(I)\right]} \tag{40}$$

Substituting (35), (36), (38), (39), and (40) into the HJB equation simplifies to as in (41)–(43), shown at the bottom of the page.

As can be seen from (41)-(43), the unary function with I as the independent variable is the solution of the HJB equation:

$$\begin{aligned} V_P(I) &= a_1 I + b_1 \\ V_E(I) &= a_2 I + b_2 \\ V_G(I) &= a_3 I + b_3 \end{aligned} \tag{44}$$

where $a_1, a_2, a_3, b_1, b_2, b_3$ are constants to be solved, which can be obtained by (44):

$$\begin{aligned} V_P'(I) &= \frac{dV_P(I)}{dI} = a_1 \\ V_E'(I) &= \frac{dV_E(I)}{dI} = a_2 \\ V_G'(I) &= \frac{dV_G(I)}{dI} = a_3 \end{aligned} \tag{45}$$

Substituting (44), (45), into (41)-(43) and organizing gives as in (46)–(48), shown at the bottom of the next page.

According to the previous assumptions, (46)-(48) are satisfied for all $I \geq 0$, and thus the parameter values of a_1, a_2, a_3, b_1, b_2, b_3 can be obtained respectively:

$$\begin{aligned} a_1 &= \frac{\alpha\omega}{\mu+\delta} \\ a_2 &= \frac{\beta\omega}{\mu+\delta} \\ a_3 &= \frac{(1-\alpha-\beta)\omega}{\mu+\delta} \end{aligned}$$

$$\begin{aligned} b_1 &= \frac{\alpha\pi_0}{\mu} + \frac{\alpha\left(2-\alpha-2\beta\right)f_P\left[\eta_P\left(\mu+\delta\right)+\lambda_P\omega\right]^2}{4\mu\left(k_Pf_P+2\right)\left(\mu+\delta\right)^2} \\ &\quad + \frac{\alpha\left(2-2\alpha-\beta\right)\left[\eta_E\left(\mu+\delta\right)+\lambda_E\omega\right]^2}{2\mu k_E\left(\mu+\delta\right)^2} \\ &\quad + \frac{\alpha(1-\alpha-\beta)\left[\eta_G\left(\mu+\delta\right)+\lambda_G\omega\right]^2}{\mu k_G\left(\mu+\delta\right)^2} \\ b_2 &= \frac{\beta\pi_0}{\mu} + \frac{\beta\left(2-\alpha-2\beta\right)f_P\left[\eta_P\left(\mu+\delta\right)+\lambda_P\omega\right]^2}{2\mu\left(k_Pf_P+2\right)\left(\mu+\delta\right)^2} \\ &\quad + \frac{\beta\left(2-2\alpha-\beta\right)\left[\eta_E\left(\mu+\delta\right)+\lambda_E\omega\right]^2}{4\mu k_E\left(\mu+\delta\right)^2} \\ &\quad + \frac{\beta(1-\alpha-\beta)\left[\eta_G\left(\mu+\delta\right)+\lambda_G\omega\right]^2}{\mu k_G\left(\mu+\delta\right)^2} \\ b_3 &= \frac{(1-\alpha-\beta)\pi_0}{\mu} + \frac{(2-\alpha-2\beta)^2 f_P\left[\eta_P\left(\mu+\delta\right)+\lambda_P\omega\right]^2}{8\mu\left(k_Pf_P+2\right)\left(\mu+\delta\right)^2} \\ &\quad + \frac{\left(2-2\alpha-\beta\right)^2\left[\eta_E\left(\mu+\delta\right)+\lambda_E\omega\right]^2}{8\mu k_E\left(\mu+\delta\right)^2} \\ &\quad + \frac{\left(1-\alpha-\beta\right)^2\left[\eta_G\left(\mu+\delta\right)+\lambda_G\omega\right]^2}{2\mu k_G\left(\mu+\delta\right)^2} \end{aligned} \tag{49}$$

Substitute a_1, a_2, a_3 into (35), (36), and (38), the optimal data resource sharing effort levels of digital platform enterprises, cooperative enterprises, and the government in the Stackelberg game scenario, respectively:

$$A_{P_2}^* = \frac{(2-\alpha-2\beta)f_P\left[\eta_P\left(\mu+\delta\right)+\lambda_P\omega\right]}{2\left(k_Pf_P+2\right)\left(\mu+\delta\right)} \tag{50}$$

$$A_{E_2}^* = \frac{\left(2-2\alpha-\beta\right)\left[\eta_E\left(\mu+\delta\right)+\lambda_E\omega\right]}{2k_E\left(\mu+\delta\right)} \tag{51}$$

$$\begin{aligned} \mu V_P(I) &= \left[\alpha\omega - \delta V_P'(I)\right]I + \alpha\pi_0 + \frac{f_P\left[\alpha\eta_P + \lambda_P V_P'(I)\right]\left[(2-\alpha-2\beta)\,\eta_P + \lambda_P\left(V_P'(I)+2V_G'(I)\right)\right]}{4(k_Pf_P+2)} \\ &\quad + \frac{\left[\alpha\eta_E + \lambda_E V_P'(I)\right]\left[(2-2\alpha-\beta)\,\eta_E + \lambda_E\left(V_E'(I)+2V_G'(I)\right)\right]}{2k_E} \\ &\quad + \frac{\left[\alpha\eta_G + \lambda_G V_P'(I)\right]\left[(1-\alpha-\beta)\eta_G + \lambda_G V_G'(I)\right]}{k_G} \end{aligned} \tag{41}$$

$$\begin{aligned} \mu V_E(I) &= \left[\beta\omega - \delta V_E'(I)\right]I + \beta\pi_0 + \frac{f_P\left[\beta\eta_P + \lambda_P V_E'(I)\right]\left[(2-\alpha-2\beta)\,\eta_P + \lambda_P\left(V_P'(I)+2V_G'(I)\right)\right]}{2(k_Pf_P+2)} \\ &\quad + \frac{\left[\beta\eta_E + \lambda_E V_E'(I)\right]\left[(2-2\alpha-\beta)\,\eta_E + \lambda_E\left(V_E'(I)+2V_G'(I)\right)\right]}{4k_E} \\ &\quad + \frac{\left[\beta\eta_G + \lambda_G V_E'(I)\right]\left[(1-\alpha-\beta)\eta_G + \lambda_G V_G'(I)\right]}{k_G} \end{aligned} \tag{42}$$

$$\begin{aligned} \mu V_G(I) &= \left[(1-\alpha-\beta)\omega - \delta V_G'(I)\right]I + (1-\alpha-\beta)\pi_0 \\ &\quad + \frac{f_P\left[(2-\alpha-2\beta)\,\eta_P + \lambda_P\left(V_P'(I)+2V_G'(I)\right)\right]^2}{8\left(k_Pf_P+2\right)} \\ &\quad + \frac{\left[(2-2\alpha-\beta)\,\eta_E + \lambda_E\left(V_E'(I)+2V_G'(I)\right)\right]^2}{8k_E} \\ &\quad + \frac{\left[(1-\alpha-\beta)\eta_G + \lambda_G V_G'(I)\right]^2}{2k_G} \end{aligned} \tag{43}$$

$$A_{G_2}^{*}=\frac{(1-\alpha-\beta)\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]}{k_G(\mu+\delta)} \tag{52}$$

$$\sigma=\frac{2-3\alpha-2\beta}{2-\alpha-2\beta} \tag{53}$$

$$\theta=\frac{2-2\alpha-3\beta}{2-2\alpha-\beta} \tag{54}$$

Substituting the values in (49) into (44), the optimal revenue functions of digital platform enterprises, cooperative enterprises, and the government in the Stackelberg game scenario are obtained, respectively:

$$\begin{aligned}V_{P_2}(I)^{*}=&\frac{\alpha\omega}{\mu+\delta}I+\frac{\alpha\pi_0}{\mu}\\&+\frac{\alpha(2-\alpha-2\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{4\mu(k_Pf_P+2)(\mu+\delta)^2}\\&+\frac{\alpha(2-2\alpha-\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{2\mu k_E(\mu+\delta)^2}\\&+\frac{\alpha(1-\alpha-\beta)\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{\mu k_G(\mu+\delta)^2}\end{aligned} \tag{55}$$

$$\begin{aligned}V_{E_2}(I)^{*}=&\frac{\beta\omega}{\mu+\delta}I+\frac{\beta\pi_0}{\mu}\\&+\frac{\beta(2-\alpha-2\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{2\mu(k_Pf_P+2)(\mu+\delta)^2}\\&+\frac{\beta(2-2\alpha-\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{4\mu k_E(\mu+\delta)^2}\\&+\frac{\beta(1-\alpha-\beta)\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{\mu k_G(\mu+\delta)^2}\end{aligned} \tag{56}$$

$$\begin{aligned}V_{G_2}(I)^{*}=&\frac{(1-\alpha-\beta)\omega}{\mu+\delta}I+\frac{(1-\alpha-\beta)\pi_0}{\mu}\\&+\frac{(2-\alpha-2\beta)^2f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{8\mu(k_Pf_P+2)(\mu+\delta)^2}\\&+\frac{(2-2\alpha-\beta)^2\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{8\mu k_E(\mu+\delta)^2}\\&+\frac{(1-\alpha-\beta)^2\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{2\mu k_G(\mu+\delta)^2}\end{aligned} \tag{57}$$

Thus, the optimal data resource sharing revenue for the digital innovation ecosystem under this model can be obtained as follows:

$$\begin{aligned}V_2(I)^{*}=&\frac{\omega I}{\mu+\delta}+\frac{\pi_0}{\mu}\\&+\frac{\left[4-(\alpha+2\beta)^2\right]f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{8\mu(k_Pf_P+2)(\mu+\delta)^2}\\&+\frac{\left[4-(2\alpha+\beta)^2\right]\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{8\mu k_E(\mu+\delta)^2}\\&+\frac{\left[1-(\alpha+\beta)^2\right]\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{2\mu k_G(\mu+\delta)^2}\end{aligned} \tag{58}$$

C. COLLABORATIVE GAME MODEL

In the collaborative game scenario, digital platform enterprises, cooperative enterprises, and the government work together to enhance data resource sharing capability and improve information development levels. The three parties, as an organic whole, determine the optimal decision for all three parties to maximize the overall benefits of the digital innovation ecosystem. At this point, the objective function shared by digital platform enterprises, cooperative enterprises, and the government is:

$$\begin{aligned}J&=J_P+J_E+J_G\\&=\max_{A_P,A_E,A_G\geq 0}\int_0^{\infty}e^{-\mu t}[(\pi_0+\eta_PA_P+\eta_EA_E+\eta_GA_G+\omega I)\\&\quad-\left(\frac{k_P}{2}+\frac{1}{f_P}\right)A_P^2-\frac{k_E}{2}A_E^2-\frac{k_G}{2}A_G^2]dt\end{aligned} \tag{59}$$

$$\begin{aligned}\mu(a_1I+b_1)=&(\alpha\omega-\delta a_1)I+\alpha\pi_0+\frac{f_P(\alpha\eta_P+\lambda_Pa_1)\left[(2-\alpha-2\beta)\eta_P+\lambda_P(a_1+2a_3)\right]}{4(k_Pf_P+2)}\\&+\frac{(\alpha\eta_E+\lambda_Ea_1)\left[(2-2\alpha-\beta)\eta_E+\lambda_E(a_2+2a_3)\right]}{2k_E}\\&+\frac{(\alpha\eta_G+\lambda_Ga_1)\left[(1-\alpha-\beta)\eta_G+\lambda_Ga_3\right]}{k_G}\end{aligned} \tag{46}$$

$$\begin{aligned}\mu(a_2I+b_2)=&(\beta\omega-\delta a_2)I+\beta\pi_0+\frac{f_P(\beta\eta_P+\lambda_Pa_2)\left[(2-\alpha-2\beta)\eta_P+\lambda_P(a_1+2a_3)\right]}{2(k_Pf_P+2)}\\&+\frac{(\beta\eta_E+\lambda_Ea_2)\left[(2-2\alpha-\beta)\eta_E+\lambda_E(a_2+2a_3)\right]}{4k_E}\\&+\frac{(\beta\eta_G+\lambda_Ga_2)\left[(1-\alpha-\beta)\eta_G+\lambda_Ga_3\right]}{k_G}\end{aligned} \tag{47}$$

$$\begin{aligned}\mu(a_3I+b_3)=&\left[(1-\alpha-\beta)\omega-\delta a_3\right]I+(1-\alpha-\beta)\pi_0+\frac{f_P\left[(2-\alpha-2\beta)\eta_P+\lambda_P(a_1+2a_3)\right]^2}{8(k_Pf_P+2)}\\&+\frac{\left[(2-2\alpha-\beta)\eta_E+\lambda_E(a_2+2a_3)\right]^2}{8k_E}\\&+\frac{\left[(1-\alpha-\beta)\eta_G+\lambda_Ga_3\right]^2}{2k_G}\end{aligned} \tag{48}$$

Assume that there exists a continuously differentiable and bounded revenue function $V(I)$, for the digital innovation ecosystem, all of which satisfy the following HJB equation when $I \geq 0$:

$$\mu V(I) = \max_{A_P, A_E, A_G \geq 0} [(\pi_0 + \eta_P A_P + \eta_E A_E + \eta_G A_G + \omega I) - \left(\frac{k_P}{2} + \frac{1}{f_P}\right) A_P^2 - \frac{k_E}{2} A_E^2 - \frac{k_G}{2} A_G^2 + V'(I)(\lambda_P A_P + \lambda_E A_E + \lambda_G A_G - \delta I)] \tag{60}$$

Calculate the first order partial derivative of A_P, A_E, A_G, and set them equal to zero. The solution is:

$$A_P = \frac{(\eta_P + \lambda_P V'(I))f_P}{k_P f_P + 2}$$
$$A_E = \frac{\eta_E + \lambda_E V'(I)}{k_E}$$
$$A_G = \frac{\eta_G + \lambda_G V'(I)}{k_G} \tag{61}$$

Substituting (61) into (60) simplifies to:

$$\mu V(I) = \left[\omega - \delta V'(I)\right] I + \pi_0 + \frac{f_P \left[\eta_P + \lambda_P V'(I)\right]^2}{2(k_P f_P + 2)} + \frac{\left[\eta_E + \lambda_E V'(I)\right]^2}{2k_E} + \frac{\left[\eta_G + \lambda_G V'(I)\right]^2}{2k_G} \tag{62}$$

As can be seen from (62), the unary function with I as the independent variable is the solution of the HJB equation:

$$V(I) = a_1 I + b_1 \tag{63}$$

where a_1, b_1 are the constants to be solved, which can be obtained by (63):

$$V'(I) = \frac{dV(I)}{dI} = a_1 \tag{64}$$

Substituting (63), (64) into (62) gives:

$$\mu(a_1 I + b_1) = (\omega - \delta a_1) I + \pi_0 + \frac{f_P (\eta_P + \lambda_P a_1)^2}{2(k_P f_P + 2)} + \frac{(\eta_E + \lambda_E a_1)^2}{2k_E} + \frac{(\eta_G + \lambda_G a_1)^2}{2k_G} \tag{65}$$

According to the previous assumptions, (64) is satisfied for all $I \geq 0$, and thus, the parameter values of a_1, b_1 can be obtained respectively:

$$a_1 = \frac{\omega}{\mu + \delta}$$
$$b_1 = \frac{\pi_0}{\mu} + \frac{f_P [\eta_P (\mu + \delta) + \lambda_P \omega]^2}{2\mu (k_P f_P + 2) (\mu + \delta)^2} + \frac{[\eta_E (\mu + \delta) + \lambda_E \omega]^2}{2\mu k_E (\mu + \delta)^2} + \frac{[\eta_G (\mu + \delta) + \lambda_G \omega]^2}{2\mu k_G (\mu + \delta)^2} \tag{66}$$

Substitute a_1 into (61), the optimal data resource sharing effort levels of digital platform enterprises, cooperative enterprises, and the government in the collaborative game scenario, respectively:

$$A_{P_3}^* = \frac{f_P [\eta_P (\mu + \delta) + \lambda_P \omega]}{(k_P f_P + 2)(\mu + \delta)} \tag{67}$$
$$A_{E_3}^* = \frac{\eta_E (\mu + \delta) + \lambda_E \omega}{k_E (\mu + \delta)} \tag{68}$$
$$A_{G_3}^* = \frac{\eta_G (\mu + \delta) + \lambda_G \omega}{k_G (\mu + \delta)} \tag{69}$$

Substituting the values in (65) into (63), the optimal income functions of digital platform enterprises, cooperative enterprises, and the government in the collaborative game scenario are obtained, respectively:

$$V_{P_3}(I)^* = \frac{\alpha\omega}{\mu + \delta} I + \frac{\alpha\pi_0}{\mu} + \frac{\alpha f_P [\eta_P (\mu + \delta) + \lambda_P \omega]^2}{2\mu (k_P f_P + 2)(\mu + \delta)^2} + \frac{\alpha [\eta_E (\mu + \delta) + \lambda_E \omega]^2}{2\mu k_E (\mu + \delta)^2} + \frac{\alpha [\eta_G (\mu + \delta) + \lambda_G \omega]^2}{2\mu k_G (\mu + \delta)^2} \tag{70}$$

$$V_{E_3}(I)^* = \frac{\beta\omega}{\mu + \delta} I + \frac{\beta\pi_0}{\mu} + \frac{\beta f_P [\eta_P (\mu + \delta) + \lambda_P \omega]^2}{2\mu (k_P f_P + 2)(\mu + \delta)^2} + \frac{\beta [\eta_E (\mu + \delta) + \lambda_E \omega]^2}{2\mu k_E (\mu + \delta)^2} + \frac{\beta [\eta_G (\mu + \delta) + \lambda_G \omega]^2}{2\mu k_G (\mu + \delta)^2} \tag{71}$$

$$V_{G_3}(I)^* = \frac{(1 - \alpha - \beta)\omega}{\mu + \delta} I + \frac{(1 - \alpha - \beta)\pi_0}{\mu} + \frac{(1 - \alpha - \beta) f_P [\eta_P (\mu + \delta) + \lambda_P \omega]^2}{2\mu (k_P f_P + 2)(\mu + \delta)^2} + \frac{(1 - \alpha - \beta)[\eta_E (\mu + \delta) + \lambda_E \omega]^2}{2\mu k_E (\mu + \delta)^2} + \frac{(1 - \alpha - \beta)[\eta_G (\mu + \delta) + \lambda_G \omega]^2}{2\mu k_G (\mu + \delta)^2} \tag{72}$$

Thus, the optimal data resource sharing revenue for the digital innovation ecosystem under this model can be obtained as follows:

$$V_3(I)^* = \frac{\omega}{\mu + \delta} I + \frac{\pi_0}{\mu} + \frac{f_P [\eta_P (\mu + \delta) + \lambda_P \omega]^2}{2\mu (k_P f_P + 2)(\mu + \delta)^2} + \frac{[\eta_E (\mu + \delta) + \lambda_E \omega]^2}{2\mu k_E (\mu + \delta)^2} + \frac{[\eta_G (\mu + \delta) + \lambda_G \omega]^2}{2\mu k_G (\mu + \delta)^2} \tag{73}$$

D. COMPARATIVE ANALYSIS OF MODEL RESULTS

Comparing and analyzing the optimal level of efforts and revenues of digital platform enterprises, cooperative enterprises, and the government in the three game scenarios, as well as the information development level and overall benefits of the digital innovation ecosystem, this paper obtains the relevant research propositions, and the specific propositions and the argumentation process are as follows:

Proposition 1:

$$A_{P_1}^* < A_{P_2}^* < A_{P_3}^*, A_{E_1}^* < A_{E_2}^* < A_{E_3}^*, A_{G_1}^* = A_{G_2}^* < A_{G_3}^*,$$
$$\sigma^* = \frac{A_{P_2}^* - A_{P_1}^*}{A_{P_2}^*}(0 < \sigma < \frac{2}{3}), \theta^* = \frac{A_{E_2}^* - A_{E_1}^*}{A_{E_2}^*}(0<\theta<\frac{2}{3})$$

Proof:

$$\begin{aligned} A_{P_2}^* - A_{P_1}^* &= \frac{(2-3\alpha-2\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]}{2(k_Pf_P+2)(\mu+\delta)} \\ &= \frac{2-3\alpha-2\beta}{2-\alpha-2\beta} \\ &\quad \cdot \frac{(2-\alpha-2\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]}{2(k_Pf_P+2)(\mu+\delta)} \\ &= \sigma^* \cdot A_{P_2}^* > 0 \end{aligned} \tag{74}$$

$$\begin{aligned} A_{E_2}^* - A_{E_1}^* &= \frac{(2-2\alpha-3\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]}{2k_E(\mu+\delta)} \\ &= \frac{2-2\alpha-3\beta}{2-2\alpha-\beta} \\ &\quad \cdot \frac{(2-2\alpha-\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]}{2k_E(\mu+\delta)} \\ &= A_{E_2}^* \cdot \theta^* > 0 \end{aligned} \tag{75}$$

$$A_{G_2}^* = A_{G_1}^* \tag{76}$$

$$A_{P_3}^* - A_{P_2}^* = \frac{(\alpha+2\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]}{2(k_Pf_P+2)(\mu+\delta)} > 0 \tag{77}$$

$$A_{E_3}^* - A_{E_2}^* = \frac{(2\alpha+\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]}{2k_E(\mu+\delta)} > 0 \tag{78}$$

$$A_{G_3}^* - A_{G_2}^* = \frac{(\alpha+\beta)\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]}{k_G(\mu+\delta)} > 0 \tag{79}$$

Corollary 1: The government's data resource sharing effort level stays the same in Nash's non-cooperative and Stackelberg's games. However, government incentives for digital platform enterprises and cooperative enterprises can significantly enhance their effort level, and the increase is equal to the degree of government incentives.

Proposition 2: The optimal revenues for all three types of subjects in the Stackelberg game model are more significant than in the Nash non-cooperative model. Namely $V_{P_2}(I)^* > V_{P_1}(I)^*, V_{E_2}(I)^* > V_{E_1}(I)^*, V_{G_2}(I)^* > V_{G_1}(I)^*$.

Proof:

$$\begin{aligned} &V_{P_2}(I)^* - V_{P_1}(I)^* \\ &= \frac{\alpha(2-3\alpha-2\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{4\mu(k_Pf_P+2)(\mu+\delta)^2} \\ &\quad + \frac{\alpha(2-2\alpha-3\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{2\mu k_E(\mu+\delta)^2} > 0 \end{aligned} \tag{80}$$

$$\begin{aligned} &V_{E_2}(I)^* - V_{E_1}(I)^* \\ &= \frac{\beta(2-3\alpha-2\beta)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{2\mu(k_Pf_P+2)(\mu+\delta)^2} \\ &\quad + \frac{\beta(2-2\alpha-3\beta)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{4\mu k_E(\mu+\delta)^2} > 0 \end{aligned} \tag{81}$$

$$\begin{aligned} &V_{G_2}(I)^* - V_{G_1}(I)^* \\ &= \frac{(3\alpha+2\beta-2)^2 f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{8\mu(k_Pf_P+2)(\mu+\delta)^2} \\ &\quad + \frac{(2\alpha+3\beta-2)^2\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{8\mu k_E(\mu+\delta)^2} > 0 \end{aligned} \tag{82}$$

Proposition 3: The optimal revenue in the digital innovation ecosystem is most significant in the collaborative model, next in the Stackelberg game model, and most minor in the Nash non-cooperative game model. That is $V_3(I)^* > V_2(I)^* > V_1(I)^*$.

Proof:

$$\begin{aligned} &V_2(I)^* - V_1(I)^* \\ &= \frac{(3\alpha+2\beta-2)(\alpha-2\beta-2)f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{8\mu(k_Pf_P+2)(\mu+\delta)^2} \\ &\quad + \frac{(2\alpha+3\beta-2)(-2\alpha+\beta-2)\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{8\mu k_E(\mu+\delta)^2} > 0 \end{aligned} \tag{83}$$

$$\begin{aligned} &V_3(I)^* - V_2(I)^* \\ &= \frac{(\alpha+2\beta)^2 f_P\left[\eta_P(\mu+\delta)+\lambda_P\omega\right]^2}{8\mu(k_Pf_P+2)(\mu+\delta)^2} \\ &\quad + \frac{(2\alpha+\beta)^2\left[\eta_E(\mu+\delta)+\lambda_E\omega\right]^2}{8\mu k_E(\mu+\delta)^2} \\ &\quad + \frac{(\alpha+\beta)^2\left[\eta_G(\mu+\delta)+\lambda_G\omega\right]^2}{2\mu k_G(\mu+\delta)^2} > 0 \end{aligned} \tag{84}$$

Corollary 2: The optimal incentive coefficient decreases with the increase in the benefit sharing coefficient, i.e. $\frac{\partial\sigma^*}{\partial\alpha} < 0, \frac{\partial\sigma^*}{\partial\beta} < 0, \frac{\partial\theta^*}{\partial\alpha} < 0, \frac{\partial\theta^*}{\partial\beta} < 0$.The higher the revenue sharing ratio between digital platform enterprises and cooperative enterprises, the smaller the optimal incentive coefficient of the government for the two types of subjects. At this time, the government does not need to give a large amount of subsidies to digital platform enterprises and cooperative enterprises, and the two types of subjects can also have considerable income.

Proof: It can be obtained from (53), (54) where $0 < \alpha < \frac{2}{3}, 0 < \beta < \frac{2}{3}$:

$$\begin{aligned} \frac{\partial\sigma^*}{\partial\alpha} &= -\frac{4(1-\beta)}{(2-\alpha-2\beta)^2} < 0, \frac{\partial\sigma^*}{\partial\beta} = -\frac{4\alpha}{(2-\alpha-2\beta)^2} < 0 \\ \frac{\partial\theta^*}{\partial\alpha} &= -\frac{4\beta}{(2-2\alpha-\beta)^2} < 0, \frac{\partial\theta^*}{\partial\beta} = -\frac{4(1-\alpha)}{(2-2\alpha-\beta)^2} < 0 \end{aligned} \tag{85}$$

Proposition 4: When the benefit distribution coefficients α β satisfy the following equations, the collaborative model realizes the optimal benefit of the ecosystem as a whole and makes the benefits of the three types of participating subjects Pareto-optimal.

Proof:

$$V_{P_3}(I)^* > V_{P_1}(I)^*, V_{E_3}(I)^* > V_{E_1}(I)^*, V_{G_3}(I)^* > V_{G_1}(I)^* \tag{86}$$

$$V_{P_3}(I)^* > V_{P_2}(I)^*, V_{E_3}(I)^* > V_{E_2}(I)^*, V_{G_3}(I)^* > V_{G_2}(I)^* \tag{87}$$

From Proposition 2, it follows that $V_{P_2}(I)^* > V_{P_1}(I)^*$, $V_{E_2}(I)^* > V_{E_1}(I)^*$, $V_{G_2}(I)^* > V_{G_1}(I)^*$, thus, it is only necessary to prove (87).

It can be obtained from (50)-(52) and (70)-(72) as in (88)–(90), shown at the bottom of the page.

Let $v_1 = \frac{f_P[\eta_P(\mu+\delta)+\lambda_P\omega]^2}{\mu(k_Pf_P+2)(\mu+\delta)^2}$, $v_2 = \frac{[\eta_E(\mu+\delta)+\lambda_E\omega]^2}{\mu k_E(\mu+\delta)^2}$, $v_3 = \frac{[\eta_G(\mu+\delta)+\lambda_G\omega]^2}{\mu k_G(\mu+\delta)^2}$

Then we obtain as in (91), shown at the bottom of the page.

The solution as in (92), shown at the bottom of the page.

V. SIMULATION ANALYSIS OF ALGORITHMS

According to the above analysis, it can be seen that digital platform enterprises, cooperative enterprises, and the government in different game modes, their respective optimal strategies, optimal revenues, the digital technology level of the system, as well as the overall optimal revenue of the digital innovation ecosystem, depend on the selection of the parameters of the model. Therefore, numerical simulation is carried out by MATLAB software to visualize the results and parameters of the three games, which is convenient for analysis. Referring to the scholars Ji et al. and Qin et al. [45], [46], and considering reality, the relevant parameters are set $I(0) = I_0 = 1$, $k_P = 0.6$, $k_E = 0.4$, $k_G = 0.2$, $f_P = 0.3$, $\lambda_P = 0.4$, $\lambda_E = 0.3$, $\lambda_G = 0.2$, $\delta = 0.2$, $\eta_P = 0.7$, $\eta_E = 0.6$, $\eta_G = 0.5$, $\omega = 0.4$, $\alpha = 0.4$, $\beta = 0.3$, $\mu = 0.2$, $\sigma = 0.1$, $\theta = 0.1$.

The following is obtained: $A_P^N = 0.0606$, $A_E^N = 0.675$, $A_G^N = 1.05$, $V_P^N = 5.1516$, $V_E^N = 3.458$, $V_G^N = 3.3624$,

$$\frac{\alpha f_P[\eta_P(\mu+\delta)+\lambda_P\omega]^2}{2\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{\alpha[\eta_E(\mu+\delta)+\lambda_E\omega]^2}{2\mu k_E(\mu+\delta)^2} + \frac{\alpha[\eta_G(\mu+\delta)+\lambda_G\omega]^2}{2\mu k_G(\mu+\delta)^2} - \left[\frac{\alpha(2-\alpha-2\beta)f_P[\eta_P(\mu+\delta)+\lambda_P\omega]^2}{4\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{\alpha(2-2\alpha-\beta)[\eta_E(\mu+\delta)+\lambda_E\omega]^2}{2\mu k_E(\mu+\delta)^2} + \frac{\alpha(1-\alpha-\beta)[\eta_G(\mu+\delta)+\lambda_G\omega]^2}{\mu k_G(\mu+\delta)^2}\right] \geq 0 \tag{88}$$

$$\frac{\beta f_P[\eta_P(\mu+\delta)+\lambda_P\omega]^2}{2\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{\beta[\eta_E(\mu+\delta)+\lambda_E\omega]^2}{2\mu k_E(\mu+\delta)^2} + \frac{\beta[\eta_G(\mu+\delta)+\lambda_G\omega]^2}{2\mu k_G(\mu+\delta)^2} - \left[\frac{\beta(2-\alpha-2\beta)f_P[\eta_P(\mu+\delta)+\lambda_P\omega]^2}{2\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{\beta(2-2\alpha-\beta)[\eta_E(\mu+\delta)+\lambda_E\omega]^2}{4\mu k_E(\mu+\delta)^2} + \frac{\beta(1-\alpha-\beta)[\eta_G(\mu+\delta)+\lambda_G\omega]^2}{\mu k_G(\mu+\delta)^2}\right] \geq 0 \tag{89}$$

$$\frac{(1-\alpha-\beta)f_P[\eta_P(\mu+\delta)+\lambda_P\omega]^2}{2\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{(1-\alpha-\beta)[\eta_E(\mu+\delta)+\lambda_E\omega]^2}{2\mu k_E(\mu+\delta)^2} + \frac{(1-\alpha-\beta)[\eta_G(\mu+\delta)+\lambda_G\omega]^2}{2\mu k_G(\mu+\delta)^2} - \left[\frac{(2-\alpha-2\beta)^2f_P[\eta_P(\mu+\delta)+\lambda_P\omega]^2}{8\mu(k_Pf_P+2)(\mu+\delta)^2} + \frac{(2-2\alpha-\beta)^2[\eta_E(\mu+\delta)+\lambda_E\omega]^2}{8\mu k_E(\mu+\delta)^2} + \frac{(1-\alpha-\beta)^2[\eta_G(\mu+\delta)+\lambda_G\omega]^2}{2\mu k_G(\mu+\delta)^2}\right] \geq 0 \tag{90}$$

$$\begin{cases} v_1+v_2+v_3 \geq \dfrac{(2-\alpha-2\beta)}{2}v_1 + (2-2\alpha-\beta)v_2 + 2(1-\alpha-\beta)v_3 \\ v_1+v_2+v_3 \geq (2-\alpha-2\beta)v_1 + \dfrac{(2-2\alpha-\beta)}{2}v_2 + 2(1-\alpha-\beta)v_3 \\ (1-\alpha-\beta)v_1 + (1-\alpha-\beta)v_2 + (1-\alpha-\beta)v_3 \geq \dfrac{(2-\alpha-2\beta)^2}{4}v_1 + \dfrac{(2-2\alpha-\beta)^2}{4}v_2 + (1-\alpha-\beta)^2v_3 \end{cases} \tag{91}$$

$$\begin{cases} \alpha \geq \dfrac{-4v_1^2+2v_2^2+4v_1v_2-2v_1v_3+3v_2v_3}{9v_1v_2+2v_1v_3+2v_2v_3} \\ \beta \leq \dfrac{2v_1^2-4v_2^2+4v_1v_2+3v_1v_3-2v_2v_3}{9v_1v_2+2v_1v_3+2v_2v_3} \\ \left[(\alpha+2\beta)^2-4\beta\right]v_1 + \left[(2\alpha+\beta)^2-4\alpha\right]v_2 - 2(1-\alpha-\beta)(\alpha+\beta)v_3 \leq 0 \end{cases} \tag{92}$$

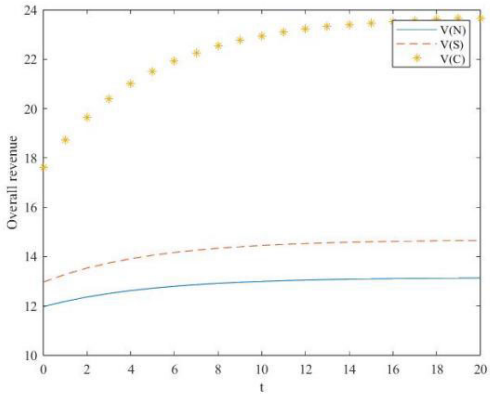


FIGURE 2. Optimal revenues for the digital innovation ecosystem.

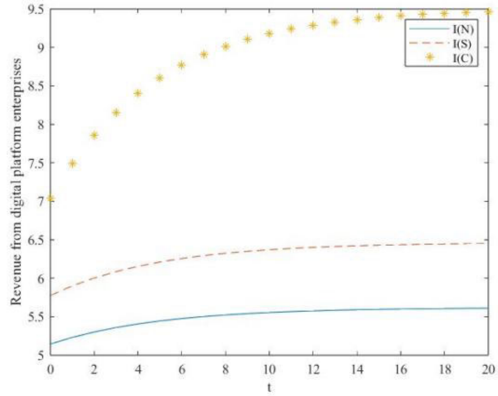


FIGURE 3. Optimal revenues of digital platform enterprises.

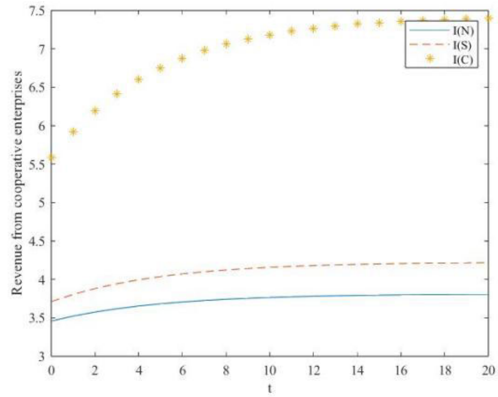


FIGURE 4. Optimal revenues of cooperative enterprises.

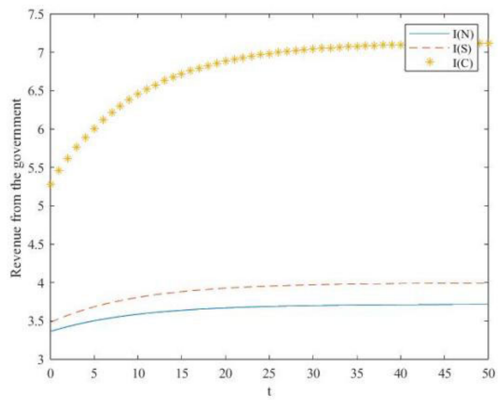


FIGURE 5. Optimal revenues of the government.

$V^N = 11.9721$, $A_P^S = 0.0757$, $A_E^S = 1.0125$, $A_G^S = 1.05$, $V_P^S = 5.7758$, $V_E^S = 3.7108$, $V_G^S = 3.4806$, $V^S = 12.9671$, $A_P^C = 0.1514$, $A_E^C = 2.25$, $A_G^C = 3.5$, $V_P^C = 7.0415$, $V_E^C = 5.2812$, $V_G^C = 5.2812$, $V^C = 17.6038$.

Therefore, Propositions 1-3 are proofed.

To further verify the conclusion, according to the expression of the particular solution function of the first-order differential equation, we can obtain the following:

$V_P^N = 5.61908 - 0.47348e^{-0.2t}$, $V_E^N = 3.81311 - 0.35511e^{-0.2t}$, $V_G^N = 3.71751 - 0.35511e^{-0.2t}$, the overall income is $V^N = 13.1558 - 1.1837e^{-0.2t}$.

$V_P^S = 6.46386 - 0.68806e^{-0.2t}$, $V_E^S = 4.22685 - 0.51605e^{-0.2t}$, $V_G^S = 3.99665 - 0.51605e^{-0.2t}$, the overall income is $V^S = 14.68725 - 1.72015e^{-0.2t}$.

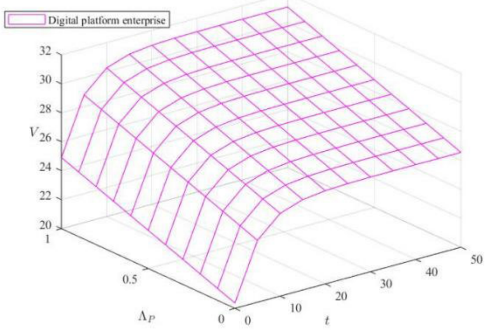
$V_P^C = 9.51262 - 2.47112e^{-0.2t}$, $V_E^C = 7.43454 - 1.85334e^{-0.2t}$, $V_G^C = 7.13454 - 1.85334e^{-0.2t}$, the overall income is $V^C = 23.7816 - 6.1778e^{-0.2t}$.

The simulation diagrams of the above model results are shown in Figs. Figs. 2-5.

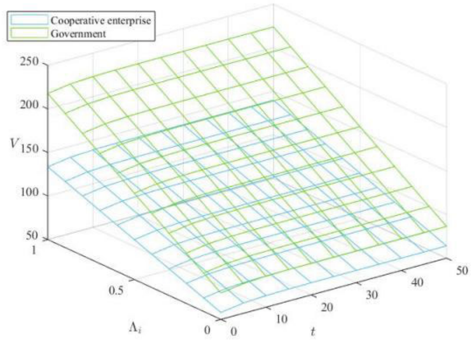
Figs. 2-5 show the trend of optimal revenues over time, with the horizontal axis being time and the vertical axis being optimal revenues. The optimal revenues of digital platform enterprises, cooperative enterprises, and the government increase over time and stabilize after reaching equilibrium. The collaborative game model outperforms the Stackelberg game model, and the Stackelberg game model outperforms the non-collaborative model, both for individual participants and the digital innovation ecosystem. By incentivizing data resource sharing between digital platform enterprises and cooperative enterprises, the government can increase the overall revenues of the system, validating the conclusions drawn from Propositions 2 and 3.

Figs. 6-9 are three-dimensional diagrams of the influence of the data resource sharing capability coefficient, the influence coefficient of effort level on digital innovation ecosystem impact, the digital technology level coefficient of digital platform enterprises, and the cost coefficient of data resource sharing on each parameter of the symbiotic collaborative innovation system under the collaborative model, with the horizontal axis showing the time and influence variables and the vertical axis showing the optimal revenues.

As seen in Figs. 6 and 7, the effect of the data resource sharing capacity coefficient and the influence coefficient of effort level on the digital innovation ecosystem is positive, with the magnitude increasing slightly over time. Furthermore, as the effort level increases, so does the sharing capacity, which is essentially the same as the effort level. In contrast, the government's sharing capacity and effort level had the

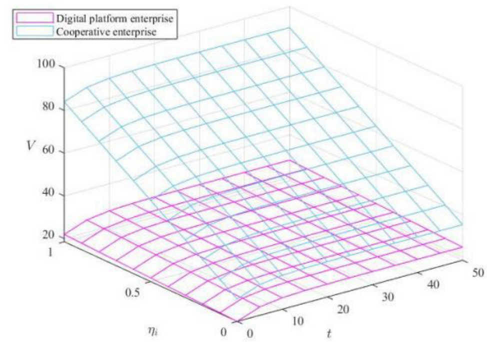


a. The effect of λ_P and t on $V_3(I)^*$

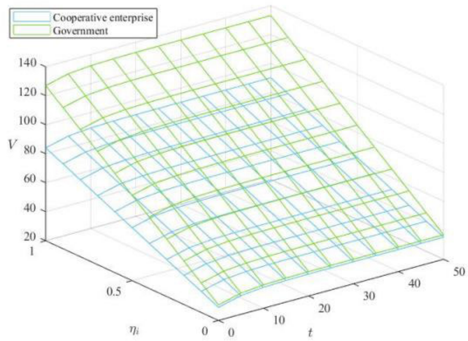


b. The effect of λ_E, λ_G and t on $V_3(I)^*$

FIGURE 6. The effect of λ_P, λ_E, λ_G and t on $V_3(I)^*$.



a. The effect of η_P, η_E and t on $V_3(I)^*$



b. The effect of η_E, η_G and t on $V_3(I)^*$

FIGURE 7. The effect of η_P, η_E, η_G and t on $V_3(I)^*$.

most significant impact on revenues, and digital platform companies had the most negligible impact. Thus, the government should actively encourage enterprises to enhance their sharing capacity to accelerate data resource sharing. For example, strengthen platform support, optimize platform functions, enrich platform sharing methods, and establish a sound sharing mechanism to make sharing more regular and institutionalized. Strengthen the communication between the government and enterprises, enrich the content of data resources, improve the talent training mechanism, and provide strong talent support and guarantees. At the same time, the government can also provide incentives to enterprises to enhance their enthusiasm for enterprise data resource sharing, efforts to share, and sharing capacity, which are subsequently enhanced so that data resource sharing in the digital innovation ecosystem realizes a virtuous cycle.

As shown in Fig. 8, the impact of digital platform enterprises' digital technology level coefficient on the revenues of digital innovation ecosystems is positive, stabilizing over time after a significant revenue increase. Digital technology eliminates the information gap to a certain extent, improves information transparency, and reduces the cost of sharing. The higher the digital technology level, the better the functionality and service level of the digital platform, which helps to enhance data resource sharing and increase revenue. However, at the same time, the problems of access to personal information, privacy, and other issues that jeopardize sharing

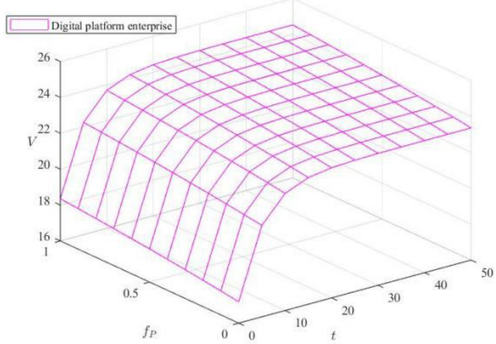
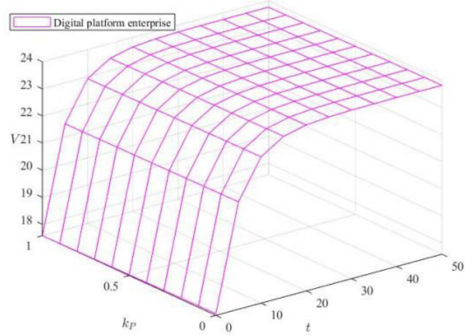


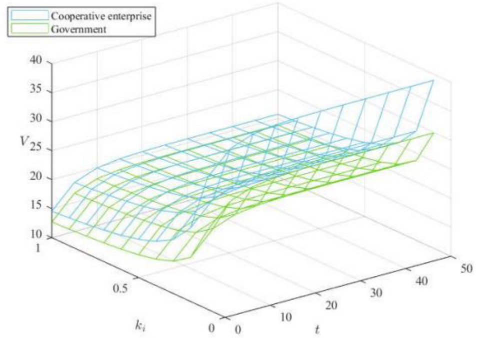
FIGURE 8. The effect of f_P and t on $V_3(I)^*$.

arising from the increased digital technology level should be avoided.

As seen in Fig. 9, the effect of the data resource sharing cost coefficient on the revenues of the digital innovation ecosystem is negative, with the magnitude increasing over time. The sharing cost of cooperative enterprises has the most significant impact on revenue. In contrast, digital platform enterprises build digital platforms through digital technology to provide sharing places and provide strong support for data resource sharing. Thus, their sharing cost has the most negligible impact on revenue. Therefore, to reduce the sharing cost and increase the revenue level, on the one hand, transparent cooperation mechanisms should be established to reduce the



a. The effect of k_P and t on $V_3(I)^*$



b. The effect of k_E, k_G and t on $V_3(I)^*$

FIGURE 9. The effect of k_P, k_E, k_G and t on $V_3(I)^*$.

friction and disputes that may be encountered during cooperation, and reasonable cooperation agreements should be formulated to protect the interests of all parties and avoid conflicts of interest. On the other hand, risk management and security are being strengthened to reduce unnecessary costs arising from risk and security issues.

VI. CONCLUSION AND IMPLICATIONS

In this paper, the differential game model is used to study the enterprise data resource sharing problem among digital platform enterprises, cooperative enterprises, and the government in the digital innovation ecosystem and analyze the optimal data resource sharing effort level, optimal revenue, ecosystem optimal revenue situation, and optimal incentive of the government to the digital platform enterprises and cooperative enterprises of the three main parties in the Nash non-cooperative, Stackelberg, and cooperative game modes. The following conclusions are obtained by comparing the equilibrium solutions and simulation results in the three modes:

(1) Under the three game models, data resource sharing effort level is positively correlated with the data resource sharing capability coefficient, the influence coefficient of effort level on the digital innovation ecosystem, the digital technology level coefficient of digital platform enterprises, and negatively correlated with the cost coefficient of data resource sharing and the elimination rate of shared data resources.

(2) In the Stackelberg game model, the data resource sharing effort levels of digital platform enterprises and cooperative enterprises are enhanced compared to the Nash non-cooperative game model, and the enhancement is equal to the government's incentive coefficient for data resource sharing between digital platform enterprises and cooperative enterprises. However, the government shares the same effort level in the Stackelberg and the Nash non-cooperative game models. In the collaborative game model, all three parties' data resource sharing effort levels are improved compared to the Stackelberg game model.

(3) The optimal revenues of the three parties and the total ecosystem revenues in Stackelberg's game model are strictly better than those in Nash's non-cooperative game model, suggesting that government incentives can increase the revenues to the ecosystem and its members. The cooperative game model strictly outperforms the Stackelberg game model by reaching the maximum value and determining a reasonable benefit distribution coefficient, which can achieve Pareto optimality.

Based on the findings of the above study, the following insights can be drawn:

(1) The collaborative game model is an effective solution for the digital innovation ecosystem to realize open sharing and high-quality development. However, it is necessary to determine a fair and reasonable benefit distribution scheme based on the different divisions of labor, efforts, and contributions of the main parties to satisfy the value acquisition goals of the main parties, to avoid "free-riding" behaviors, and to realize cooperation and common progress. To further increase the willingness to share data resources, to promote the continuation of sharing behaviors, to enhance the information development level, and to promote the continuous development of the digital innovation ecosystem.

(2) The government needs to formulate and improve relevant laws and regulations, establish regulatory agencies, and strengthen publicity and education to protect issues such as data security and privacy protection. On this basis, reasonable incentive strategies should be adopted, and economic incentive measures such as rewarding subsidies and tax concessions can be taken to promote enterprise sharing. Laws and regulations related to data resource sharing should be introduced to clarify the legality and obligations of sharing. The structure of data resources should be standardized, and a quality evaluation system should be constructed to improve the quality of data resources. Optimize and smooth the data resource sharing platform, strengthen the platform's functions, accelerate the interconnection of various platforms and other measures to improve the willingness of enterprises to share and motivate enterprises to actively share data resources.

(3) Digital platform enterprises should strengthen their digital technology level, provide a secure and convenient data resource sharing platform, strengthen data security and privacy protection and other technical means, reduce information asymmetry among enterprises, and improve

information transparency, sharing efficiency, and overall information development. For all enterprises, they should pay close attention to government policies, adjust their development strategies according to the policies, and improve their ability to collect, sort, refine, and innovate data resources. And under the incentive and leadership of the government, proactively carry out sharing, establish a good sharing and cooperation mechanism, and jointly solve the problems in the sharing process so as to realize the goal of a win-win situation for enterprises and society.

VII. PRACTICAL CONTRIBUTION

Government incentives promote enterprise data resource sharing, enabling enterprises to better understand and analyze the market situation and industry trends, assess potential risks and opportunities, and make more accurate strategic planning decisions. Help enterprises better understand user needs and behaviors, provide better products and services, and improve user satisfaction and loyalty. Strengthen the exchanges and cooperation among enterprises, break the information silo, improve the quality and accuracy of data, improve work efficiency, promote the innovation of enterprises and industries, enhance the competitiveness of enterprises, and realize the common development and progress of the industry. Promote the process of digital transformation, promote the development of digital technology and the digital economy, and facilitate the construction of the digital innovation ecosystem. Enhance information symmetry, support enterprises to achieve sustainable development goals and fulfill social responsibilities, and promote social equity and development.

VIII. RESEARCH LIMITATIONS AND PROSPECTS

The following limitations and future perspectives remain in this paper: (1) There are many participants in enterprise data resource sharing in digital innovation ecosystems. This paper only divides the participants into three subjects, namely, digital platform enterprises, cooperative enterprises, and the government. At the same time, there is a complex, competitive relationship within the subjects, and subsequent research can add other subjects and take the competitive relationship into account. (2) There are many factors affecting data resource sharing. This paper only selects some of the factors to be studied, and subsequent research can add security, the level of trust, the existence of risk, and other factors of data resource sharing to its impact. (3) This paper only considers the government's incentive mechanism for data resource sharing, and future research could further consider the government's supervision and regulation mechanism or other mechanisms.

ACKNOWLEDGMENT

The authors would like to thank the anonymous reviewers for their thoughtful suggestions and comments.

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