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Research article

Research on the data integration strategy of local governments and enterprises under central government subsidies

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Abstract: This paper uses differential game theory to study the cooperation strategy and cost-sharing of local government and enterprise data integration under central government subsidies. We use differential game theory to build game models under the three modes of cooperative cooperation, noncooperation, and bilateral cost-sharing contracts; design a profit-sharing mechanism to improve the game structure between local governments and enterprises under bilateral cost-sharing contracts; and analyze the results of the model through simulation analysis. We draw the following research conclusions. (1) Under the collaborative cooperation model, the two parties in the game have the highest degree of data integration effort and the highest level of data integration, achieving Pareto optimality. (2) The profit-sharing mechanism can improve the bilateral cost-sharing contract so that the optimal effort of local governments and enterprises to integrate data and the level of data integration reach the level under the cooperative game and benefit the two sides of the game compared with the noncooperative model. This achieves Pareto improvement. (3) The efforts of local governments and enterprises to integrate data is negatively correlated with the cost coefficient of data integration and positively correlated with the social welfare effect. The research conclusions provide a theoretical reference for formulating local government and enterprise data integration policies and improving the level of data integration in China.

Keywords: integrated data; central government subsidies; contract; differential game
Mathematics Subject Classification: 91A23

1. Introduction

In the digital economy era, data have become an important factor of production. The transformation and upgrading of traditional industries, new smart cities and digital government construction levels are highly related to the application of government-enterprise data integration. The application value of government and enterprise data and the integration and sharing of data between governments and enterprises have been highly valued by all sectors of society. As a country with a large population and economy, China is rich in data resources, but local government departments are still very common due to the complicated ownership of administrative agencies and unclear division of rights and responsibilities for derived data. In particular, the integration and circulation of data between governments and enterprises is not strong enough. The willingness of enterprises to actively integrate data with governments is not strong, the level of data integration and utilization between governments and enterprises is not high, and it is difficult to maximize the role of key elements of data. These issues have a large impact on the development of China's digital economy. It is urgent to accelerate the promotion of local governments and the integration of enterprise data to improve the level of data integration.

The existing research shows that it is difficult to communicate and share data at all levels, and it is difficult to smoothly integrate data between various departments. Fragmentation leads to the view of "information islands", which is generally accepted [1]. This view believes that the government, as the holder of massive public data, breaking through data barriers between government departments is the core foundation for building a digital government [2]. Integrated government data mainly involve information disclosure data, online government affairs data, convenience service data, and interactive platform data [3]. However, due to the special attributes of government data, there are obstacles such as technology and security protection in the data integration process [4]. Some scholars have proposed a plan for government data integration and sharing. They believe that open data policy is a guideline for the integration and sharing of government data, and its effectiveness is directly related to the level of government data integration and availability. An effective government data availability policy requires the comprehensive use of four types of policy tools, commands, incentives, capacity building, and system change, to promote the orderly development of government data integration and opening [5]. From the perspective of stakeholders, some scholars proposed that the implementation of government data integration must clarify all stakeholders in order to give full play to the active roles of all stakeholders in government data integration and better promote government data integration [6]. With the popularization of the new generation of information technology in various economic and social fields, government data, business big data, medical big data, education big data, scientific big data and data resources from other fields continue to accumulate, especially for enterprises. The most active market entity in the digital economy, the value of corporate data in promoting the rapid development of the digital economy, cannot be ignored [7,8]. Based on the great value of government and corporate data, at the second collective study meeting of the Political Bureau of the Central Committee after the 19th National Congress, General Secretary Xi Jinping stated the following: "We must strengthen government-enterprise cooperation and multiparty participation, accelerate data concentration and sharing in the public service field, and promote platform docking with the social data accumulated by enterprises to form a strong synergy of social governance". This is the first time that the central government has proposed promoting the integration of government data and enterprise data and forming a policy requirement for an integrated government-enterprise data resource system [9]. In recent years, scholars have conducted research on the integration of government and enterprise data. For example, some scholars have suggested that the integration of government data with corporate and other social data can enhance government data control capabilities, support government decision-making, and increase data dividends. Some scholars have researched the relevance and management mechanism of government-enterprise data from the perspectives of ontology and collaborative innovation theory [10–12]. Some scholars have used the evolutionary game method to study the problem of government and enterprise data integration [13]. For example, from the perspective of privacy protection, we can construct a tripartite evolutionary game model of patients, medical service institutions, and the government to explore the willingness of the tripartite participants to participate in medical data sharing or construct an evolutionary game model with governments and enterprises as the main bodies to analyze government openness. This can allow one to assess the dynamic evolutionary process of data and enterprises' use of open government data [14].

In summary, scholars have found through literature research methods and case analysis methods that the integration of government and enterprise data has gradually emerged in promoting the flow of production factors, upgrading traditional industries, and coordinating supply chains. Furthermore, scholars have analyzed policy formulation. Based on experience summaries and influencing factors, some scholars have constructed evolutionary game models with governments and enterprises as the main body and used game theory to study the application of government and enterprise data or open data strategies. This literature review found that the existing research still has the following main limitations: (1) Most existing studies only focus on a single entity of governments or enterprises and only consider the issue of data integration and sharing between governments or enterprises, ignoring that the level of data integration is jointly determined by governments, enterprises and other entities. (2) Existing research is mainly based on qualitative research such as case and empirical analysis and is supplemented by model research such as evolutionary game. Most of the research subjects' behaviors are limited to a fixed choice. That is, the strategy of governments or enterprises can only be “integration.” Alternatively, a certain strategy such as “unconformity” ignores the change of state variables and the change of the main body's strategy as the state changes. In reality, the data integration strategy of all parties in the game is constantly changing, and there is a problem of information asymmetry in the game system. Among the participants with limited rationality, all parties in the game need to achieve the final balance through interaction and dynamic changes. (3) Existing research on the integration of government and enterprise data still distinguishes the levels of government. In reality, the national data sharing and exchange system is composed of two parts: state and local governments (including the provincial and prefectural levels). Data integration is formulated with corresponding project support plans and policy preferential measures. When studying the data integration strategies of various local governments, it is necessary to consider the influence of the central government as a variable.

Considering that differential games can handle conflict, competition or cooperation between parties or multiple parties within a continuous period of time, differential games are a dynamic game model that is widely applied to supply chains [15,16], product quality [17], collaboration innovation [18], foreign investment [19], goodwill [20], network crowdsourcing default [21], pricing decisions [22,23] and other dynamic issues research; therefore, this paper chooses the differential game model. Under the long-term dynamic framework, we study the effect of the central government subsidy rate on the level of data integration and the level of data integration efforts between local governments and enterprises and explore how local governments and enterprises can design contracts to encourage both parties to increase their data integration efforts to scientifically formulate government-enterprise data integration. The sharing strategy provides a theoretical reference.

2. Basic assumptions

This article considers that the data integration system is composed of local governments (G) and enterprises (E), both of which are rational subjects. The basic assumptions are as follows:

Assumption 1. Under the background that data have become an important factor of production, D_G and D_E respectively represent the efforts of local governments and enterprises to integrate data, $D_G \geq 0, D_E \geq 0$, and the cost of integrating data between local governments and enterprises has convex characteristics. Therefore, the equation of the cost function for integrating data between local governments and enterprises is:

$$\begin{cases} C_G = \frac{1}{2}\mu_G D^2{}_G \\ C_E = \frac{1}{2}\mu_E D^2{}_E \end{cases} \tag{2.1}$$

Where $\mu_{G,} \mu_G > 0$ and $\mu_{E,} \mu_E > 0$ represent the cost coefficients of the efforts of local governments and enterprises to integrate data.

In order to promote the integration of data between local governments and enterprises and promote the circulation of data elements, the central government of China provides a solid foundation for the development of the country's digital economy. The cost coefficients shared by the central government for local governments and enterprises to integrate data are γ_G and γ_E, respectively.

Assumption 2. Local governments and enterprises actively integrate data to further break down the data barriers between local governments and enterprises and play positive roles in promoting the development and utilization of data elements. Suppose $L(t)$ is determined by the degree of effort of local governments and enterprises to integrate data, that the level of data integration of local governments and enterprises is a dynamic process of change, and the law of change satisfies the following differential equation:

$$\begin{cases} L'(t) = \lambda_G D_G + \lambda_E D_E - \delta L(t) \\ L(0) = L_0 \geq 0 \end{cases} \tag{2.2}$$

Where λ_G、 λ_E respectively represent the influence coefficient of the data integration activities of local governments and enterprises on the level of data integration. Assuming that local governments and enterprises will clean up data that is not time-sensitive over time, δ $(\delta > 0)$ represents the natural decay rate of the data integration level. $L(0)=L_0 \geq 0$, represents the level of data integration at the initial moment.

Assumption 3. Local governments and enterprises actively integrate data, which can promote the aggregation of data among different subjects, thereby promoting data circulation and utilization. This can better support the accuracy of enterprise production and operations, promote the coordinated development of supply chains, accelerate the implementation of data-driven production, and improve society. Regarding the overall welfare effects, assume that the function of the social welfare effects is:

$$\mathrm{W}(t)=\mathrm{W}_0+\nu_G D_G+\nu_E D_E+aL(t) \tag{2.3}$$

W_0 represents the initial welfare effect for society, ν_G、ν_E respectively represent the influence coefficient of the efforts of local governments and enterprises to integrate data on the social welfare effect, and α represents the coefficient of the influence of the level of data integration on the social welfare effect.

Assumption 4. Let the coefficient of the effect of social welfare on the income of local government and enterprise integrated data be $y, y>0$. Then, the total income brought by integrated local government and enterprise data is $yW(\mathrm{t})$. The total benefits of data integration between local governments and enterprises are distributed between the two, and the distribution ratios are x , $1-x$ ($0<x<1$), respectively. In an infinite time horizon, the local government and the enterprise have the same discount factor ρ $(\rho>0)$, and both goals are to seek the optimal strategy for maximizing their own income in an infinite time horizon.

Table 1. Symbol meaning and description.

Symbol	Meaning
D_G	Degree of effort of a local government to integrate data, which is the *control functions*, implemented by Government
D_E	The level of effort of an enterprise to integrate data, which is the *control functions*, implemented by Enterprises
C_G	The cost of local government data integration
C_E	The cost of enterprise data integration
γ_G	The proportion of the cost shared by the central government for data integration for local governments
γ_E	The central government's share of the cost of integrating data for enterprises
$L_D(\mathrm{t})$	Data integration level at all times
λ_G	The coefficient of the influence of local government data integration on the level of data integration
λ_E	The coefficient of the influence of enterprise data integration on the level of data integration
W_0	Initial social welfare effect
ν_G	The coefficient of the influence of local government data integration on the social welfare effect
ν_E	The coefficient of the influence of enterprise data integration on the social welfare effect
α	The coefficient of the influence of the data integration level on the social welfare effect
y	Coefficients of the social welfare effects on the benefits of integrating data between local governments and enterprises
x	Proportion of revenue from local government data integration
$1-x$	Proportion of revenue from enterprise data integration

Continued on next page

Symbol	Meaning
δ	The natural decay rate of the data integration level, where
ρ	Discount factor

3. Model construction and analysis basic assumptions

Starting from the different types of game parties, game strategies can be summarized into three modes: the collaborative cooperation mode, the noncooperative mode, and the bilateral cost-sharing contract mode. Through the construction of a two-party game model with local governments and enterprises as the main body, research on central government subsidies can be conducted. The effect of the rate of government subsidies on the level of data integration, the benefits of local governments and enterprises, and how local governments and enterprises can design contracts under central government subsidies to encourage both parties to increase their data integration efforts are discussed.

3.1. Collaborative cooperation model (scenario C)

Under the collaborative cooperation model, local governments and enterprises determine their own optimal strategies based on the premise of maximizing overall interests and improve the level of data integration in a collaborative manner. The objective function is as follows:

$$\pi=\int_0^{\infty} e^{-\rho t}\left\{y\left(\mathrm{W}_0+v_G D_G^C+v_E D_E^C+\alpha L(\mathrm{t})\right)-\frac{1}{2}(1-\gamma_G)\mu_G\left(D_G^C(t)\right)^2-\frac{1}{2}(1-\gamma_E)\mu_E\left(D_E^C(t)\right)^2\right\}\mathrm{dt} \quad (3.1)$$

Proposition 1. The equilibrium result under the collaborative cooperation mode is as follows.

(1) The optimal equilibrium strategy for local governments and enterprises is:

$$\left(D_G^{C^*}, D_E^{C^*}\right)=\left(\frac{y\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)}, \frac{y\left[v_E(\rho+\delta)+\alpha\lambda_E\right]}{\mu_E(1-\gamma_E)(\rho+\delta)}\right) \quad (3.2)$$

(2) The optimal trajectory of the data integration level is:

$$\begin{cases} L^{C^*}=\dfrac{U^{C^*}}{\delta}+\left(L_0-\dfrac{U^{C^*}}{\delta}\right)\mathrm{e}^{-\delta \mathrm{t}} \\ U^{C^*}=\dfrac{y\lambda_G\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)}+\dfrac{y\lambda_E\left[v_E(\rho+\delta)+\alpha\lambda_E\right]}{\mu_E(1-\gamma_E)(\rho+\delta)} \end{cases} \quad (3.3)$$

(3) The profit optimal value function of the system is:

$$V^{C^*}(L)=\frac{y\alpha}{\rho+\delta}L+\frac{yW_0}{\rho}+\frac{y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2}+\frac{y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \quad (3.4)$$

Proof. In order to obtain the optimal solution of the cooperative game, a continuous bounded differential function $V(R)$, which satisfies the Hamilton-Jacobi-Bellman (HJB) equation, is constructed.

$$\rho V^{C}=\max_{(D_G,D_E)}\left\{y\left(W_0+v_G D_G^C+v_E D_E^C+\alpha L\right)-\frac{1}{2}(1-\gamma_G)\mu_G D_G^{C2}-\frac{1}{2}(1-\gamma_E)\mu_E D_E^{C2}+\frac{\partial V^C}{\partial L}\left(\lambda_G D_G^C+\lambda_E D_E^C-\delta L\right)\right\} \tag{3.5}$$

Equation (3.5) is the concave function of (D_G, D_E). The partial derivative of (D_G, D_E) is solved, and its right end is set equal to 0. The optimal strategy set of local governments and enterprises can be obtained as:

$$\left(D_G^C, D_E^C\right)=\left(\frac{yv_G+\lambda_G\frac{\partial V^C}{\partial L}}{\mu_G(1-\gamma_G)},\frac{yv_E+\lambda_E\frac{\partial V^C}{\partial L}}{\mu_E(1-\gamma_E)}\right) \tag{3.6}$$

Equation (3.6) is substituted into Eq (3.5) to obtain:

$$\rho V^C=\left(y\alpha-\delta\frac{\partial V^C}{\partial L}\right)L+yW_0+\frac{\left(y\upsilon_G+\lambda_G\frac{\partial V^C}{\partial L}\right)^2}{2\mu_G(1-\gamma_G)}+\frac{\left(y\upsilon_E+\lambda_E\frac{\partial V^C}{\partial L}\right)^2}{2\mu_E(1-\gamma_E)} \tag{3.7}$$

According to the functional form of Eq (3.7), it can be inferred that the solution of V^C is a linear equation of two variables with respect to L_D. Let the solution of V^C be:

$$V^C(L)=m_1L+m_2 \tag{3.8}$$

Here, m_1、m_2 are constants. $V^C(L)$ and its partial derivative with respect to L are inserted into Eq (3.8), similar terms are sorted and merged, and the undetermined coefficient method is used to solve:

$$\begin{cases} m_1=\dfrac{y\alpha}{\rho+\delta} \\ m_2=\dfrac{yW_0}{\rho}+\dfrac{y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2}+\dfrac{y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \end{cases} \tag{3.9}$$

Equation (3.9) is substituted into Eq (3.6) to obtain the optimal behavioural strategy of local governments and enterprises, namely, Eq (3.2). Eq (3.2) is substituted into Eq (1.2) and the first-order linear ordinary differential equation is solved to obtain the optimal level of the data integration trajectory as:

$$\begin{cases} L'(t)=U^C-\delta L(t) \\ L(0)=0 \end{cases} \tag{3.10}$$

Here, $U^{C}=\lambda_{G}D_{G}^{C^{*}}+\lambda_{E}D_{E}^{C^{*}}=\frac{y\lambda_{G}\left[v_{G}(\rho+\delta)+\alpha\lambda_{G}\right]}{\mu_{G}(1-\gamma_{G})(\rho+\delta)}+\frac{y\lambda_{E}\left[v_{E}(\rho+\delta)+\alpha\lambda_{E}\right]}{\mu_{E}(1-\gamma_{E})(\rho+\delta)}$. Eq (3.10) is solved to obtain the expression of data integration level L^{C}, namely, Eq (3.3)

Substituting Eq (3.9) into Eq (3.8), the system's profit optimal value function is obtained, that is, Eq (3.4).

Proposition 1 is proved.

3.2. Noncooperative mode (case N)

In the noncooperative mode, local governments and enterprises all aim to maximize their own interests. In this case, the objective function equations of local governments and enterprises are respectively as follows:

$$\pi_{G}=\int_{0}^{\infty}e^{-\rho t}\left\{xy\left(\mathrm{W}_{0}+v_{G}D_{G}^{N}+v_{E}D_{E}^{N}+\alpha L(\mathrm{t})\right)-\frac{1}{2}(1-\gamma_{G})\mu_{G}\left(D_{G}^{N}(t)\right)^{2}\right\}\mathrm{d}t \tag{3.11}$$

$$\pi_{E}^{N}=\int_{0}^{\infty}e^{-\rho t}\left\{(1-x)y\left(\mathrm{W}_{0}+v_{G}D_{G}^{N}+v_{E}D_{E}^{N}+\alpha L(\mathrm{t})\right)-\frac{1}{2}(1-\gamma_{E})\mu_{E}\left(D_{E}^{N}(t)\right)^{2}\right\}\mathrm{dt} \tag{3.12}$$

Proposition 2. The equilibrium result under the noncooperative situation of local government and enterprise is as follows.

(1) The optimal equilibrium strategy for integrating data between local governments and enterprises is:

$$\left(D_{G}^{N^{*}},D_{E}^{N^{*}}\right)=\left(\frac{xy\left[v_{G}(\rho+\delta)+\alpha\lambda_{G}\right]}{\mu_{G}(1-\gamma_{G})(\rho+\delta)},\frac{(1-x)y\left[v_{E}(\rho+\delta)+\alpha\lambda_{E}\right]}{\mu_{E}(1-\gamma_{E})(\rho+\delta)}\right) \tag{3.13}$$

(2) The optimal trajectory of the data integration level is:

$$\begin{cases}L^{N^{*}}=\frac{U^{N^{*}}}{\delta}+\left(L_{0}-\frac{U^{N^{*}}}{\delta}\right)\mathrm{e}^{-\delta\mathrm{t}}\\ U^{N^{*}}=\frac{\lambda_{G}xy\left[v_{G}(\rho+\delta)+\alpha\lambda_{G}\right]}{\mu_{G}(1-\gamma_{G})(\rho+\delta)}+\frac{\lambda_{E}(1-x)y\left[v_{E}(\rho+\delta)+\alpha\lambda_{E}\right]}{\mu_{E}(1-\gamma_{E})(\rho+\delta)}\end{cases} \tag{3.14}$$

(3) The profit optimal value functions of local governments and enterprises are:

$$V_{G}^{N^{*}}(L)=\frac{xy\alpha}{\rho+\delta}L+\frac{xyW_{0}}{\rho}+\frac{x^{2}y^{2}\left[v_{G}(\rho+\delta)+\alpha\lambda_{G}\right]^{2}}{2\rho\mu_{G}(1-\gamma_{G})(\rho+\delta)^{2}}+\frac{x(1-x)y^{2}\left[v_{E}(\rho+\delta)+\alpha\lambda_{E}\right]^{2}}{\rho\mu_{E}(1-\gamma_{E})(\rho+\delta)^{2}} \tag{3.15}$$

$$V_{E}^{N^{*}}(L)=\frac{(1-x)y\alpha}{\rho+\delta}L+\frac{(1-x)yW_{0}}{\rho}+\frac{x(1-x)y^{2}\left[v_{G}(\rho+\delta)+\alpha\lambda_{G}\right]^{2}}{\rho\mu_{G}(1-\gamma_{G})(\rho+\delta)^{2}}+\frac{(1-x)^{2}y^{2}\left[v_{E}(\rho+\delta)+\alpha\lambda_{E}\right]^{2}}{2\rho\mu_{E}(1-\gamma_{E})(\rho+\delta)^{2}} \tag{3.16}$$

$$V^{N^*}(L)=\frac{y\alpha}{\rho+\delta}L+\frac{yW_0}{\rho}+\frac{x(2-x)y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2}+\frac{(1-x^2)y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \quad (3.17)$$

Proof. A continuous bounded differential function $V_i(R), i\in(D,E)$ that satisfies the Hamilton-Jacobi-Bellman (HJB) equation for all $R\geq 0$ is constructed, and a Markov refined Nash equilibrium for noncooperative games is obtained.

The HJB equation of local governments and enterprises is:

$$\rho V_G^N=\max_{(D_G,D_E)}\left\{xy\left(W_0+v_GD_G^N+v_ED_E^N+\alpha L\right)-\frac{1}{2}(1-\gamma_G)\mu_GD_G^{N2}+\frac{\partial V_G^N}{\partial L_D}\left(\lambda_GD_G^N+\lambda_ED_E^N-\delta L\right)\right\} \quad (3.18)$$

$$\rho V_E^N=\max_{(D_G,D_E)}\left\{(1-x)y\left(W_0+v_GD_G^N+v_ED_E^N+\alpha L\right)-\frac{1}{2}(1-\gamma_E)\mu_ED_E^{N2}+\frac{\partial V_E^N}{\partial L}\left(\lambda_GD_G^N+\lambda_ED_E^N-\delta L\right)\right\} \quad (3.19)$$

Equations (3.18) and (3.19) concern the concave functions of D_G and D_E, respectively. The partial derivative of D_G for Eq (3.18) and the partial derivative of D_E for Eq (3.19) are solved, and the right end is set to 0. The optimal strategy set of the government and enterprise is:

$$\left(D_G^N,D_E^N\right)=\left(\frac{xyv_G+\lambda_G\frac{\partial V_G^N}{\partial L}}{\mu_G(1-\gamma_G)},\frac{(1-x)yv_E+\lambda_E\frac{\partial V_E^N}{\partial L}}{\mu_E(1-\gamma_E)}\right) \quad (3.20)$$

Equation (3.20) is substituted into Eqs (3.18) and (3.19), the max symbol is eliminated, and sorting is conducted:

$$\rho V_G^N=\left(xy\alpha-\delta\frac{\partial V_G^N}{\partial L}\right)L+xyW_0+\frac{\left(xy\upsilon_G+\lambda_G\frac{\partial V_G^N}{\partial L}\right)^2}{2\mu_G(1-\gamma_G)}+\frac{\left(xy\upsilon_E+\lambda_E\frac{\partial V_G^N}{\partial L}\right)\left[(1-x)y\upsilon_E+\lambda_E\frac{\partial V_E^N}{\partial L}\right]}{\mu_E(1-\gamma_E)} \quad (3.21)$$

$$\rho V_E^N=\left((1-x)y\alpha-\delta\frac{\partial V_E^N}{\partial L}\right)L+(1-x)yW_0+\frac{\left((1-x)y\upsilon_E+\lambda_E\frac{\partial V_E^N}{\partial L}\right)^2}{2\mu_E(1-\gamma_E)}+\frac{\left(xy\upsilon_G+\lambda_G\frac{\partial V_G^N}{\partial L}\right)\left[(1-x)y\upsilon_G+\lambda_G\frac{\partial V_E^N}{\partial L}\right]}{\mu_G(1-\gamma_G)} \quad (3.22)$$

According to the functional form of Eqs (3.21) and (3.22), it can be inferred that the solutions of V_G^N and V_E^N are linear equations of two variables about L_D, and the solutions of V_G^N and V_E^N are, respectively:

$$V_G^N(L)=b_1L+b_2 \quad (3.23)$$

$$V_E^N(L)=c_1L+c_2 \quad (3.24)$$

Here, b_1, b_2, c_1, c_2 are constants. $V_G^N(L)$, $V_E^N(L)$ and their partial derivatives with respect to L is inserted into Eqs (3.21) and (3.22); Similar terms are sorted and merged, and the method of undetermined coefficients is used to solve:

$$\begin{cases} b_1 = \dfrac{xy\alpha}{\rho+\delta} \\ b_2 = \dfrac{xyW_0}{\rho} + \dfrac{x^2y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2} + \dfrac{x(1-x)y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \end{cases} \tag{3.25}$$

$$\begin{cases} c_1 = \dfrac{(1-x)y\alpha}{\rho+\delta} \\ c_2 = \dfrac{(1-x)yW_0}{\rho} + \dfrac{x(1-x)y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{\rho\mu_G(1-\gamma_G)(\rho+\delta)^2} + \dfrac{(1-x)^2y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \end{cases} \tag{3.26}$$

Substituting Eqs (3.25) and (3.26) into Eq (3.20), the optimal strategy set of local governments and enterprises can be obtained, namely, Eq (3.13).

Substituting Eq (3.13) for the optimal strategy of local governments and enterprises into Eq (2.2), we solve the first-order linear ordinary differential equation to obtain the expression of the data integration level L^N:

$$\begin{cases} L'(t) = U^N - \delta L(t) \\ L(0) = 0 \end{cases} \tag{3.27}$$

Here, $U^N = \lambda_G D_G^{N^*} + \lambda_E D_E^{N^*} = \dfrac{\lambda_G xy\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)}, \dfrac{\lambda_E(1-x)y\left[v_E(\rho+\delta)+\alpha\lambda_E\right]}{\mu_E(1-\gamma_E)(\rho+\delta)}$, and Eq (3.27) is solved to obtain the optimal level expression, that is, Eq (3.14).

Substituting the values of b_1, b_2, c_1 and c_2 into Eqs (3.23) and (3.24), the optimal income function expressions of local governments and enterprises can be obtained, namely, Eqs (3.15) and (3.16).

Proposition 2 shows that local governments and enterprises maximize their own interests as their decision-making goals, and the benefits of both parties in the game are lower than those in the collaborative cooperation mode. Therefore, whether the cost-sharing contract will improve the benefits of the game subject and the strategy choice are discussed.

3.3. Model based on bilateral cost-sharing contract (Scenario S)

This section is based on the bilateral cost-sharing contract. Under the premise that the local government bears the cost proportional to β for the enterprise and the enterprise bears the cost proportional to θ for the local government, a differential game model with local governments and enterprises as the main bodies is constructed. In this case, the objective function equations of local governments and enterprises are as follows:

$$\pi_G^S=\int_0^{\infty}e^{-\rho t}\left\{xy\left(\mathrm{W}_0+\nu_G D_G^S+\nu_E D_E^S+\alpha L(\mathrm{t})\right)-\frac{1}{2}(1-\gamma_G-\theta)\mu_G\left(D_G^S(t)\right)^2-\frac{1}{2}\beta\mu_E\left(D_E^S(t)\right)^2\right\}\mathrm{dt} \quad (3.28)$$

$$\pi_E^S=\int_0^{\infty}e^{-\rho t}\left\{(1-x)y\left(\mathrm{W}_0+\nu_G D_G^S+\nu_E D_E^S+\alpha L(\mathrm{t})\right)-\frac{1}{2}(1-\gamma_E-\beta)\mu_E\left(D_E^S(t)\right)^2-\frac{1}{2}\theta\mu_G\left(D_G^S(t)\right)^2\right\}\mathrm{dt} \quad (3.29)$$

Proposition 3. The equilibrium result based on the bilateral cost-sharing contract is as follows.

(1) The optimal proportion of integrated data cost shared by the local government for the enterprise, the optimal proportion of integrated data cost shared by the enterprise for the local government, and the optimal degree of effort of the local government and the enterprise are:

$$\begin{cases}\theta^*=(1-x)(1-\lambda_G)\\ \beta^*=x(1-\lambda_E)\end{cases} \quad (3.30)$$

$$\left(D_G^{S^*},D_E^{S^*}\right)=\left(\frac{y\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)},\frac{y\left[v_E(\rho+\delta)+\alpha\lambda_E\right]}{\mu_E(1-\gamma_E)(\rho+\delta)}\right) \quad (3.31)$$

(2) The optimal trajectory of the data integration level is:

$$\begin{cases}L^{S^*}=\dfrac{U^{S^*}}{\delta}+\left(L_0-\dfrac{U^{S^*}}{\delta}\right)\mathrm{e}^{-\delta\mathrm{t}}\\ U^{S*}=\dfrac{\lambda_G y\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)}+\dfrac{\lambda_E y\left[v_E(\rho+\delta)+\alpha\lambda_E\right]}{\mu_E(1-\gamma_E)(\rho+\delta)}\end{cases} \quad (3.32)$$

(3) The profit optimal value function and total income of local governments and enterprises are:

$$V_G^{S^*}(L)=\frac{xy\alpha}{\rho+\delta}L+\frac{xyW_0}{\rho}+\frac{xy^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2}+\frac{xy^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \quad (3.33)$$

$$V_E^{S^*}(L)=\frac{(1-x)y\alpha}{\rho+\delta}L+\frac{(1-x)yW_0}{\rho}+\frac{(1-x)\mathrm{y}^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2}+\frac{(1-\mathrm{x})\mathrm{y}^2\left[\upsilon_G(\rho+\delta)+\lambda_G\alpha\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2} \quad (3.34)$$

$$V^{S^*}(L)=\frac{y\alpha}{\rho+\delta}L+\frac{yW_0}{\rho}+\frac{y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2}+\frac{y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \quad (3.35)$$

Proof. Construct a continuous bounded differential function $V_i(R), i\in(D,E)$ where all $R\geq 0$ satisfy the Hamilton-Jacobi-Bellman (HJB) equation and obtain the Markov refined Nash equilibrium of the noncooperative game.

The HJB equations of local governments and enterprises are, respectively:

$$\rho V_G^S = \max_{(D_G,D_E)}\left\{xy\left(W_0+\nu_G D_G^S+\nu_E D_E^S+\alpha L\right)-\frac{1}{2}\left(1-\gamma_G-\theta\right)\mu_G D_G^{S2}-\frac{1}{2}\beta\mu_E D_E^{S2}+\frac{\partial V_G^S}{\partial L}\left(\lambda_G D_G D_G^S+\lambda_E D_E^S-\delta L\right)\right\} \tag{3.36}$$

$$\rho V_E^S = \max_{(D_G,D_E)}\left\{\left(1-x\right)y\left(W_0+\nu_G D_G^S+\nu_E D_E^S+\alpha L\right)-\frac{1}{2}\left(1-\gamma_E-\beta\right)\mu_E D_E^{S2}-\frac{1}{2}\theta\mu_G D_G^{S2}+\frac{\partial V_E^N}{\partial L}\left(\lambda_G D_G^S+\lambda_E D_E^S-\delta L\right)\right\} \tag{3.37}$$

Equations (3.36) and (3.37) are the concave functions of D_G and D_E, respectively. The partial derivative of D_G is solved for Eq (3.36), the partial derivative of D_E is solved for Eq (3.37), and the right end is set equal to 0. The optimal strategy set of governments and enterprises is:

$$\left(D_G^S, D_E^S\right)=\left(\frac{xy\nu_G+\lambda_G\frac{\partial V_G^S}{\partial L}}{\mu_G\left(1-\gamma_G-\theta\right)},\frac{\left(1-x\right)y\nu_E+\lambda_E\frac{\partial V_E^S}{\partial L}}{\mu_E\left(1-\gamma_E-\beta\right)}\right) \tag{3.38}$$

When the decision-making situation after the introduction of the bilateral cost-sharing contract and the optimal decision-making behaviour of the local government and the enterprise under the collaborative cooperation model are equal, strategic coordination between the local government and the enterprise can be realized, which is reflected in the model as $D_G^S = D_G^{C^*}$ and $D_E^S = D_G^{C^*}$. The solution is:

$$\begin{cases}\theta = 1-\lambda_G-\dfrac{\left(1-\gamma_G\right)\left(\rho+\delta\right)\left(xy\nu_G+\lambda_G\frac{\partial V_G^S}{\partial L}\right)}{y\left[\nu_G\left(\rho+\delta\right)+\alpha\lambda_G\right]}\\ \beta = 1-\lambda_E-\dfrac{\left(1-\gamma_E\right)\left(\rho+\delta\right)\left[\left(1-x\right)y\nu_E+\lambda_E\frac{\partial V_E^S}{\partial L}\right]}{y\left[\nu_E\left(\rho+\delta\right)+\alpha\lambda_E\right]}\end{cases} \tag{3.39}$$

Substituting Eqs (3.38) and (3.39) into Eqs (3.36) and (3.37), we obtain

$$\rho V_G^S=\left(xy\alpha-\delta\frac{\partial V_G^S}{\partial L}\right)L+xyW_0+\frac{\left(xy\nu_G+\lambda_G\frac{\partial V_G^S}{\partial L}\right)^2}{2\mu_G\left(1-\gamma_G-\theta\right)}+\frac{\left(xy\upsilon_E+\lambda_E\frac{\partial V_G^S}{\partial L}\right)\left[\left(1-x\right)y\upsilon_E+\lambda_E\frac{\partial V_E^S}{\partial L}\right]}{\mu_E\left(1-\gamma_E-\beta\right)}-\frac{\beta\left[\left(1-x\right)y\upsilon_E+\lambda_E\frac{\partial V_E^S}{\partial L}\right]^2}{2\mu_E\left(1-\gamma_E-\beta\right)^2} \tag{3.40}$$

$$\rho V_E^S=\left(\left(1-x\right)y\alpha-\delta\frac{\partial V_E^S}{\partial L}\right)L+\left(1-x\right)yW_0+\frac{\left(\left(1-x\right)y\upsilon_E+\lambda_E\frac{\partial V_E^S}{\partial L_D}\right)^2}{2\mu_E\left(1-\gamma_E-\beta\right)}+\frac{\left(xy\upsilon_G+\lambda_G\frac{\partial V_G^S}{\partial L}\right)\left[\left(1-x\right)y\upsilon_G+\lambda_G\frac{\partial V_E^S}{\partial L}\right]}{\mu_G\left(1-\gamma_G-\theta\right)}-\frac{\theta\left(xy\upsilon_G+\lambda_G\frac{\partial V_G^S}{\partial L}\right)^2}{2\mu_G\left(1-\gamma_G-\theta\right)^2} \tag{3.41}$$

According to the functional form of Eqs (3.40) and (3.41), it can be inferred that the solutions of V_G^S and V_E^S are the linear equations of two variables of L_D. Let the functional forms of V_G^S and V_E^S be:

$$V_G^S\left(L\right)=f_1L+f_2 \tag{3.42}$$

$$V_E^S\left(L\right)=g_1L+g_2 \tag{3.43}$$

Here, f_1, f_2, g_1 and g_2 are constants. $V_G^S\left(L\right)$, $V_E^S\left(L\right)$ and their partial derivatives with respect to L is inserted into Eqs (3.40) and (3.41); similar terms are sorted and merged; and the method of undetermined coefficients is used to solve:

$$\begin{cases} f_1=\dfrac{xy\alpha}{\rho+\delta} \\ f_2=\dfrac{xyW_0}{\rho}+\dfrac{x^2y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G-\theta)(\rho+\delta)^2}+\dfrac{x(1-x)y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{\rho\mu_E(1-\gamma_E-\beta)(\rho+\delta)^2}-\dfrac{\beta(1-x)^2y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E-\beta)^2(\rho+\delta)^2} \end{cases} \quad (3.44)$$

$$\begin{cases} g_1=\dfrac{(1-x)y\alpha}{\rho+\delta} \\ g_2=\dfrac{(1-x)yW_0}{\rho}+\dfrac{(1-x)^2y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E-\beta)(\rho+\delta)^2}+\dfrac{x(1-x)y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{\rho\mu_G(1-\gamma_G\text{-}\theta)(\rho+\delta)^2}-\dfrac{\theta x^2y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G\text{-}\theta)^2(\rho+\delta)^2} \end{cases} \quad (3.45)$$

Substitute Eqs (3.44) and (3.45) into Eq (3.39) to obtain $\beta^*=x(1-\lambda_E)$ and $\theta^*=(1-x)(1-\lambda_G)$, and substitute β^* and θ^* into Eqs (3.44) and (3.45).

Obtain f_1, f_2, g_1 and g_2. That is,

$$\begin{cases} f_1^*=\dfrac{xy\alpha}{\rho+\delta} \\ f_2^*=\dfrac{xyW_0}{\rho}+\dfrac{xy^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2}+\dfrac{xy^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} \end{cases} \quad (3.46)$$

$$\begin{cases} g_1^*=\dfrac{(1-x)y\alpha}{\rho+\delta} \\ g_2^*=\dfrac{(1-x)yW_0}{\rho}+\dfrac{(1-x)y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2}+\dfrac{(1-x)y^2\left[\upsilon_G(\rho+\delta)+\lambda_G\alpha\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2} \end{cases} \quad (3.47)$$

Substituting Eqs (3.46) and (3.47) into Eq (3.38), the optimal degree of data integration between local governments and enterprises is obtained, which is Eq (3.31). Substituting the optimal strategy of local governments and enterprises of Eq (3.31) into Eq (2.2), the first-order linear ordinary differential equation is solved to obtain the expression of the data integration level L^S:

$$\begin{cases} L'(t)=U^S-\delta L(t) \\ L(0)=0 \end{cases} \quad (3.48)$$

Here, $U^S=\lambda_G D_G^{S^*}+\lambda_E D_E^{S^*}=\dfrac{\lambda_G y\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)}+\dfrac{\lambda_E y\left[v_E(\rho+\delta)+\alpha\lambda_E\right]}{\mu_E(1-\gamma_E)(\rho+\delta)}$. Solving Eq (3.48) obtains the optimal level of government-enterprise data fusion L^S, that is, Eq (3.32).

Substituting the values of f_1^*, f_2^* and g_2^* into Eqs (3.42) and (3.43), the optimal income of local governments and enterprises and their total income function expressions can be obtained, namely, Eqs (3.33)–(3.35).

Proposition 3 is proved.

4. Comparative analysis of model results

By comparing and analysing the results of the two-party game model between local governments and enterprises, we can obtain the comparison results of the integration data strategy, data integration level and income situation of local governments and enterprises and summarize the following inferences.

Corollary 1. (1) Comparison results of the best efforts of local governments to integrate data: $D_G^{C^*} = D_G^{S^*} > D_G^{N^*}$. (2) Comparison results of the best effort of enterprises to integrate data: $D_E^{C^*} = D_E^{S^*} > D_E^{N^*}$. (3) In the case of a bilateral cost-sharing contract, the local government's cost-sharing ratio for the enterprise is $\theta^* = (1-x)(1-\lambda_G)$, and the optimal proportion of data integration costs shared by local governments for enterprises is $\beta^* = x(1-\lambda_E)$.

Proof. Eqs (3.2), (3.13) and (3.31) show

$$D_G^{C^*} = \frac{y\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)},\ D_G^{N^*} = \frac{xy\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)},\ D_G^{S^*} = \frac{y\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)},$$

$$D_G^{C^*} - D_G^{S^*} = 0,$$

$$D_G^{C^*} - D_G^{N^*} = \frac{(1-x)y\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)} > 0,$$

so,

$$D_G^{C^*} = D_G^{S^*} > D_G^{N^*}.$$

The same can be obtained: $D_E^{C^*} = D_E^{S^*} > D_E^{N^*}$.

The proof is complete.

Corollary 1 shows that compared with the noncooperative model, after the introduction of bilateral cost-sharing contracts, the efforts of local governments and enterprises to integrate data have been improved and reached the level of effort in the case of collaborative cooperation. It is verified from a dynamic perspective that bilateral cost-sharing contracts are effective at improving the effectiveness of the efforts of local governments and enterprises to integrate data. Collaboration between local governments and enterprises is a good mechanism to increase the efforts of both parties to integrate data, which can promote the integration of government and enterprise data, thereby improving the level of data integration and achieving a win-win situation.

Corollary 2. Comparison result of the optimal trajectory of the data integration level: $L_D^C = L_D^S > L_D^N$.

Proof. From the optimal level of data integration in the three decision-making situations, that is, Eqs (3.3), (3.14) and (3.32), we can see

$$U^C - U^S = 0,$$

$$U^C - U^N = \frac{(1-x)y\lambda_G\left[v_G(\rho+\delta)+\alpha\lambda_G\right]}{\mu_G(1-\gamma_G)(\rho+\delta)} + \frac{xy\lambda_E\left[v_E(\rho+\delta)+\alpha\lambda_E\right]}{\mu_E(1-\gamma_E)(\rho+\delta)} > 0,$$

so,

$$L^C = L^S > L^N.$$

The proof is complete.

Corollary 2 shows that in contrast to the noncooperative model, the introduction of bilateral cost-sharing contracts in the game system of local governments and enterprises improves the level of data integration and reaches the level of the collaborative cooperation model.

Corollary 3. The comparison result of the total system profit is as follows: $V^C(L) = V^S(L) > V^N(L)$.

Proof. From the total revenues of the system under the three decision-making situations, namely, Eqs (3.4), (3.17) and (3.35), we can see that

$$V^C(L) - V^S(L) = 0,$$

$$V^C(L) - V^N(L) = \frac{(x-1)^2 y^2\left[v_G(\rho+\delta)+\alpha\lambda_G\right]^2}{2\rho\mu_G(1-\gamma_G)(\rho+\delta)^2} + \frac{x^2 y^2\left[v_E(\rho+\delta)+\alpha\lambda_E\right]^2}{2\rho\mu_E(1-\gamma_E)(\rho+\delta)^2} > 0,$$

therefore,

$$V^C(L) = V^S(L) > V^N(L).$$

The proof is complete.

Corollary 3 shows that from the perspective of system profits, the collaborative cooperation model and the situation based on bilateral cost-sharing contracts have the largest system profits, and the proposal of introducing bilateral cost-sharing contracts is closer to the actual situation. Compared with the noncooperative model, it achieves Pareto improvement. However, in the case of bilateral cost-sharing contracts, it cannot be determined whether the profits of local governments and enterprises are higher than those in the noncooperative model. Therefore, a profit-sharing mechanism is designed to improve the cost-sharing contract.

5. Profit-sharing mechanism and simulation analysis

5.1. Profit-sharing mechanism

After the introduction of the bilateral cost-sharing contract, the total revenues of the system improved compared with the noncooperative situation and reached the level of system revenues in the collaborative cooperation situation. However, there is no guarantee that the benefits of local governments and enterprises can achieve parity compared with the noncooperative situation. Improvement is sought. In order to realize that local governments and enterprises are willing to share costs in the game process of introducing bilateral cost-sharing contracts, profit-sharing contracts are introduced.

Suppose that when the bilateral cost-sharing contract is introduced, the profit ratio obtained by the local government is $\tau\left(0<\tau<1\right)$ and the profit ratio obtained by the enterprise is $1-\tau$. The incomes of the local government and the enterprise being greater than those in the noncooperative situation is the prerequisite for their choice of cost-sharing strategy. Then, the local government's retained profits are $\underline{V_G^S}=V_G^{N^*}$; similarly, the enterprise’s retained profits are $\underline{V_E^S}=V_E^{N^*}$. The profit distribution ratio of local governments and enterprises when introducing bilateral cost-sharing contracts must meet the following conditions:

$$\begin{cases}\tau V^{S^*}\geq \underline{V_G^N} \\ \left(1-\tau\right)V^{S^*}\geq \underline{V_E^N}\end{cases} \tag{5.1}$$

The equation is solved to obtain $\frac{V_G^N}{V^{S^*}}\leq\tau\leq 1-\frac{V_E^N}{V^{S^*}}$. $\underline{\tau}=\frac{V_G^N}{V^{S^*}}$ and $\bar{\tau}=1-\frac{V_E^N}{V^{S^*}}$. Then, the profit distribution ratio range of local governments and enterprises is $\left[\underline{\tau},\bar{\tau}\right]$. As rational subjects, local governments and enterprises aim to maximize their own interests. Therefore, the local government hope that the value of τ is close to $\bar{\tau}$, and the enterprise hope that the value of τ is close to $\underline{\tau}$. The profit distribution ratio of local governments and enterprises to the total revenue of the system is determined by their respective bargaining powers. The profit distribution ratio of the two parties can be determined according to the “discount factor” in the Rubinstein bargaining model [24]. The discount factor represents the negotiation ability of a game player. The larger the discount factor and the stronger eqfactors of local governments and enterprises are η_G and η_E, respectively, and according to Rubinstein bargaining model theory [25,26], the profit distribution ratios of local governments and enterprises are, respectively:

$$\begin{cases}\tau=\frac{\eta_E\left(1-\eta_G\right)}{1-\eta_E\eta_G}\left(\bar{\tau}-\underline{\tau}\right)+\underline{\tau} \\ \left(1-\tau\right)=1-\frac{\eta_E\left(1-\eta_G\right)}{1-\eta_E\eta_G}\left(\bar{\tau}-\underline{\tau}\right)-\underline{\tau}\end{cases} \tag{5.2}$$

Therefore, the profits of local governments and enterprises in the case of introducing bilateral cost-sharing contracts are, respectively,

$$\begin{cases}V_G^S=\left[\frac{\eta_E\left(1-\eta_G\right)}{1-\eta_E\eta_G}\left(\bar{\tau}-\underline{\tau}\right)+\underline{\tau}\right]V^{S^*} \\ V_E^S=\left[1-\frac{\eta_E\left(1-\eta_G\right)}{1-\eta_E\eta_G}\left(\bar{\tau}-\underline{\tau}\right)-\underline{\tau}\right]V^{S^*}\end{cases} \tag{5.3}$$

5.2. Simulation analysis

In order to prove the scientific nature of the model and the effectiveness of the bilateral cost-sharing contract and profit-sharing mechanism, this paper uses the MATLAB software to simulate and analyze the model results. The values of the parameters in the simulation analysis are the following: $\lambda_G = \lambda_E = 0.6$, $L_0 = 5$, $\delta = 0.1$, $\mu_G = \mu_E = 2$, $W_0 = 1$, $v_G = v_E = \alpha = 0.5$, $y = 10$, $x = 0.6$, $\rho = 0.9$, and $\gamma_G = \gamma_E = 0.1$.

Figures 1 and 2 describe the data integration level and the change trend of the total income of local governments and enterprises, respectively, in the three situations. Figure 1 shows that compared with the noncooperative model, the data integration level after the introduction of the bilateral cost-sharing contract has been improved to the level of the collaborative cooperation model. When the initial data integration level L_0 is less than the stable state of the system (the level reached after the game), the data integration level will gradually increase over time and converge to a stable state. Figure 2 shows that the total revenues of local governments and enterprises when introducing bilateral cost-sharing contracts is equal to the total revenue under the collaborative cooperation model, and higher than the total revenues under the noncooperative model. Figures 1 and 2, related to the level of data integration and the change trend of the total revenue of local governments and enterprises show that the introduction of bilateral cost sharing contracts is an effective incentive measure, that is, when the central government provides a certain percentage of data integration costs for local governments and enterprises, local governments and enterprises share data integration costs by sharing data integration technology, financial subsidies and other incentives, which can effectively improve the efforts of local governments and enterprises to integrate data, thereby increasing the level of data integration and total revenues.

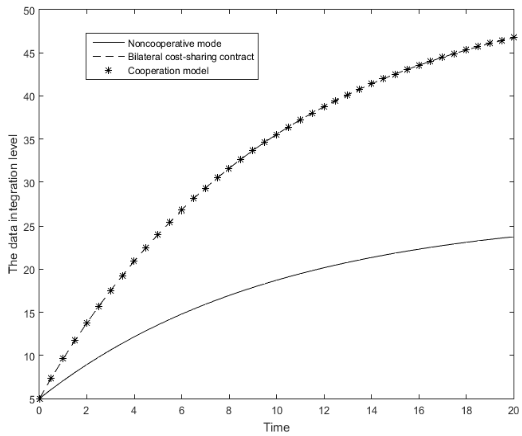

Figure 1. Data integration level in three situations.

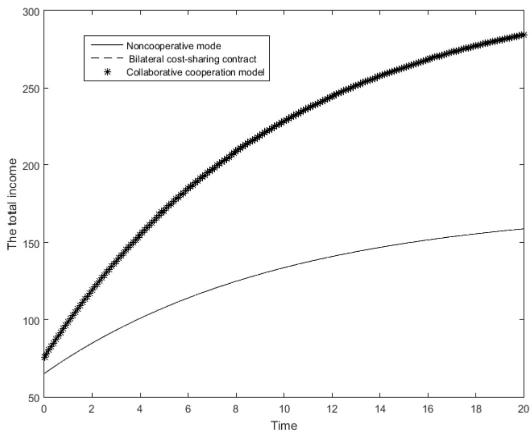

Figure 2. The total income of local governments and enterprises in the three scenarios.

Figures 3 and 4 respectively describe the revenue trends and comparisons of local governments and enterprises when the model and the introduction of bilateral cost sharing contracts are introduced. Figure 3 shows the revenue curve of local governments in the case of non-cooperation and the introduction of bilateral cost-sharing contracts. There is an intersection, which shows that the benefits of local governments when they introduce bilateral cost-sharing contracts may be lower than the benefits under noncooperative situations. Figure 4 shows that compared with the noncooperative situation, the profits of enterprises after introducing bilateral cost-sharing contracts have greatly improved. In order to ensure the effectiveness of the bilateral cost-sharing contract, it is necessary to design a profit-sharing mechanism to ensure that the benefits of local governments and enterprises are higher than those in noncooperative situations. Figures 5 and 6 show that the profits of local governments and enterprises after introducing the profit-sharing mechanism are higher than those under the noncooperative model, which indicates that the profit-sharing mechanism is an effective supplement to the bilateral cost-sharing contract and can incentivize local governments to intensify data integration with enterprises and further promote data integration between the government and enterprises.

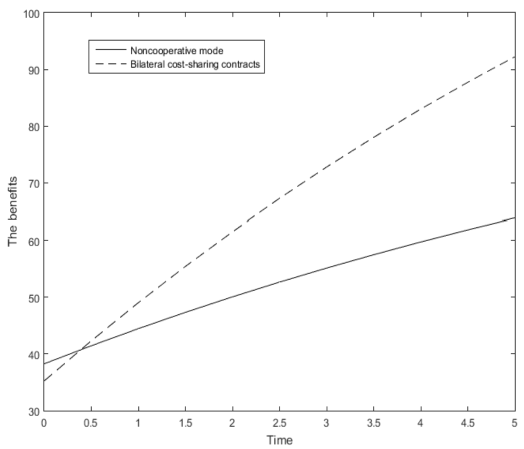

Figure 3. Local government benefits in the case of noncooperative and bilateral cost-sharing contracts.

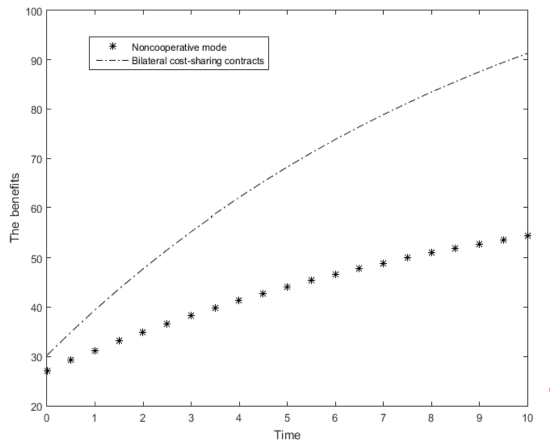

Figure 4. Business benefits in the case of noncooperative and bilateral cost-sharing contracts.

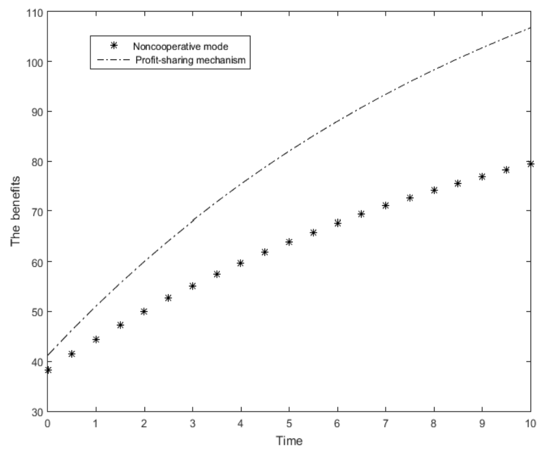

Figure 5. Local government revenue under the noncooperative and profit-sharing mechanism.

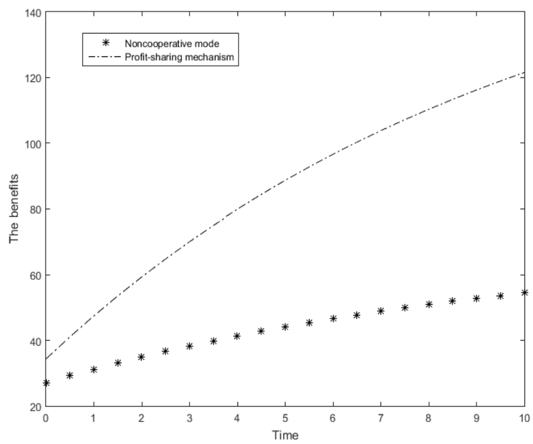

Figure 6. Corporate income under the noncooperative and profit-sharing mechanism.

6. Research conclusions and policy recommendations

This article considers the impact of central government subsidies, constructs a two-party game model with local governments and enterprises as the main bodies, studies the dynamic strategies of local governments and enterprises integrating data, and designs a profit-sharing mechanism to compensate for the lack of bilateral cost-sharing contracts. Through the above research, the following conclusions and suggestions are obtained.

(1) In the noncooperative mode, local governments and enterprises aim to maximize their own interests, the effort to integrate data is the lowest, and the level of data integration is the lowest. In the collaborative cooperation mode, local governments and enterprises aim to maximize the overall benefits. At this time, the efforts of the two parties in the game to integrate data and the level of data integration are the highest, achieving Pareto optimality. Local governments and enterprises are prone to "free-riding" behavior by one party in the situation of collaborative cooperation, and local governments and enterprises cannot reach a stable cooperative relationship consciously. The efforts of local governments and enterprises to integrate data and the level of data integration are positively correlated with the central government subsidy rate. The higher the central government subsidy rate is, the stronger the enthusiasm of local governments and enterprises to integrate data. Therefore, the establishment of a scientific and effective central government subsidy policy plays an important role in improving the level of integration and utilization of government and enterprise data in China and accelerating the marketization of data elements. It is recommended that the project subsidy mechanism of the central government and incentive policies for local governments and enterprises be introduced. This will better promote the integration and sharing of data between government and enterprises.

(2) The bilateral cost-sharing contract under the profit-sharing mechanism can coordinate the strategies of local governments and enterprises so that the optimal effort of local governments and enterprises to integrate data and the level of data integration reach the level under the cooperative game and establish the game between the two parties. Compared with the noncooperative model, income has improved, realizing Pareto improvement. It is necessary to formulate policies and rules for the integration of government-enterprise data. As a leader, local governments take the lead in designing a profit-sharing mechanism that meets the real situation, breaking the information barrier between local governments and enterprises, and ensuring that the optimal benefits of both parties are higher than those of the noncooperative model. This is done in order to better mobilize the enthusiasm of local governments and enterprises to integrate data and improve the level of data integration and utilization between governments and enterprises.

(3) The efforts of local governments and enterprises to integrate data decreases as their integrated data cost coefficient, the impact coefficients of integrated data on the level of data integration (λ_G and λ_E) and the impact coefficient of integrated data on social welfare effects (ν_G and ν_E) increase. In addition, other parameters are positively correlated. The results show that the cost of integrating data between local governments and enterprises is one of the reasons why their willingness to integrate data is not high. Therefore, further accelerating the level of open sharing of government public data, connecting government public data platforms and enterprise data platforms well, and reducing the costs of data circulation technology and institutional transactions between governments and enterprises are of important practical significance to promote the integration of government and enterprise data. Furthermore, the intervention of central government subsidies can change the cost structures of local governments and enterprises, increase the enthusiasm of local governments and enterprises to integrate data, and further improve the level of data integration and utilization.

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Conflict of interest

The authors declare that they have no competing interests.

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