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Research article

# Game analysis of enterprise data sharing from a supply chain perspective

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A R T I C L E I N F O

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A B S T R A C T

[Research Purpose] In the era of the digital economy, there is an urgent need to explore solutions to various problems faced by enterprises in their digital transformation, such as the lack of data resources, data silos, and information asymmetry within supply chains. [Method/Contribution] Leveraging evolutionary game theory and adopting a supply chain perspective, this study integrates the government and upstream/downstream enterprises into a unified analysis framework. In this study, a three-party evolutionary game model under government coordination aimed at fostering data openness and sharing among supply chain enterprises is constructed. Simulation analyses are conducted on decision-making strategies concerning data sharing between the government and supply chain enterprises across different scenarios. [Research Conclusion] It is observed that the high level of benefits and low costs associated with data sharing incentivize supply chain enterprises to actively open and share their data. Notably, government incentives significantly encourage data openness among these enterprises by subsidizing the cost of data sharing, "especially evident when the incentive coefficient exceeds 0.6," thereby guiding them toward collaborative data-sharing initiatives. Finally, it is also found that data sharing further promotes the digital transformation of the supply chain, optimizing decision-making processes, resource allocation, and operational efficiency. Through data sharing, better forecasting, inventory management, and risk mitigation strategies can be implemented. Moreover, data sharing fosters collaboration among supply chain partners enhances transparency and trust, and makes the supply chain more synchronized and responsive, which leads to value cocreation within the supply chain, with downstream enterprises being more incentivized than upstream enterprises by this value cocreation.

## 1. Introduction

The digital economy is a significant driving force for current industrial and economic development. According to the Global Digital Economy White Paper by the China Academy of Information and Communications Technology, in 2022, the digital economies of five countries namely, the United States, China, Germany, Japan, and South Korea contributed 58% of their GDP, with digital industrial scale accounting for 86.4% of the digital economy. The "Overall Plan for Digital China Construction", released in 2023, emphasizes the consolidation of digital infrastructure, the establishment of a mature digital market system, and utilization of digital technology to empower economic development, facilitating the digital transformation process for enterprises. While existing research consistently

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demonstrates that digital transformation enhances the core competitiveness of enterprises by reducing operating costs [1], and improving total factor productivity [2], among other aspects, numerous challenges exist in the implementation of such transformations in practice.

However, in actual practice, the advancement of enterprise transformation faces numerous challenges, especially within the digital transformation process, such as data bottlenecks, information asymmetry, and data silos that lead to difficulties in decision-making, reduced efficiency, decreased market agility, inhibited innovation, and increased security risk [3,4]. These issues significantly impede the progress of digital transformation [5]. Scholars have highlighted that data sharing is pivotal in addressing challenges like data silos and information asymmetry in enterprise digital transformation [3–6]. Based on this premise, this study attempts to integrate the government and supply chain enterprises into a unified framework, focusing on constructing models that delve into issues like data silos and information asymmetry within digital transformation for in-depth analysis [7]. The aim is to explore the pathways on which to address the challenges and difficulties in data-related aspects during enterprise digital transformation through open data sharing. Additionally, this study seeks to determine how to incentivize enterprises to engage in data sharing.

Currently, research on open data sharing is focused mainly on the bellow following areas, both domestically and internationally.

The first stream of research is that on the open sharing of government data. Wang Fang et al. [8] found that the open sharing of government data can promote innovation and economic growth and effectively improve the government's collaborative governance ability from an intelligence perspective [9]. Huang Xianhai et al. [10] used propensity score matching and double-difference methods to explore the impact of the open sharing of government data on the level of urban innovation and found that the open sharing of government data can significantly promote the improvement of the urban innovation level. Han Pu et al. [11] explored the key factors concerning the degree of government data openness by constructing an indicator system, and the results showed that the laws and regulations of open data sharing are the core factors affecting open government data sharing. Deng Song et al. [12] used fuzzy-set qualitative comparative analysis to find that enterprise and public pressure, basic security, and financial security are the external driving factors affecting the degree of government data openness. Zhang et al. [13] discussed the mechanism of realizing the value of open government data and found that the quantity and quality of data development affects the realization of the value of open government data. Furthermore, Song Yi et al. [14] examined data governance in the European Union to provide empirical insights for open government data sharing in China.

The second stream involves the discussion of data opening and sharing for government-enterprise cooperation. Li Ruolan [15] suggested that data classification and transmission standards should be determined to promote the further release of data value, form a two-way flow of government and enterprise data, and promote economic development. Song Weiwei et al. [16] explored the open sharing of data from both the government and enterprises in the European Union and found that the open sharing of data in government-enterprise cooperation can improve the efficiency of economic operations and achieve a win-win situation for both parties. Z. Fan et al. [6] explored the open sharing of data in government-enterprise cooperation based on a stochastic differential game and found that the appropriate level of the open sharing of data can significantly improve societal welfare and enhance the degree of competitiveness of enterprises [17]. LEE, Jung Wan et al. [18] explored the status quo in which enterprises and governments face barriers to data access and are reluctant to share data and found that two-way data sharing between governments and enterprises can help the two parties make better decisions and effectively reduce information costs. Song Weiwei et al. [19] found that the open sharing of data between government and nongovernment sectors under blockchain technology can promote the efficiency of collaboration between the two sides and, to a certain extent, can alleviate the phenomenon of data silos as well as other phenomena.

The third stream involves the exploration of open data sharing among enterprises. Chi Renyong et al. [20] discovered that data sharing can help enterprises reduce the number of information asymmetry issues and enhance their competitiveness. Fu Ying et al. [21] through data from the World Bank, verified the positive correlation between enterprise data sharing and digitalization and innovation performance, indicating that enterprise data sharing significantly improves enterprise performance [22]. Tan, J et al. [23] utilizing a two-party evolutionary game, identified strategic choices in enterprise information sharing and found that interenterprise information sharing not only enhances industrial synergies but also boosts enterprise profitability [24].

The fourth stream pertains to research on supply chain information sharing. In practice, information asymmetry is prevalent, significantly impeding the healthy development of supply chains [25]. Zheng, KQ et al. [26] found that effective data sharing can enhance the production efficiency of supply chain enterprises [27,28]. Yang Jinyu et al. discovered the collaborative and contagious effects of enterprise data openness on supply chains [29,30]. The contagious effect of data openness among upstream enterprises motivates data sharing within the supply chain, which can ameliorate information asymmetry, foster value cocreation, and enhance the efficiency of supply chain enterprises [31]. Shen LX et al. [32] utilizing evolutionary game theory, explore how to promote proactive information sharing among port cold chain logistics enterprises [33–35], revealing positive spillover effects of upstream enterprise strategies on downstream enterprises.

Through a literature review, it is widely acknowledged that open data sharing significantly enhances the efficiency of enterprises, governments, societies, and economic operations. Presently, numerous scholars are focusing on government data [36,37] and the open sharing of government-enterprise data [6], employing primarily qualitative research methods such as literature reviews and case analyses [37]. However, these methods, based on scholars' experiential rules, may carry subjective biases, potentially limiting the universality of their conclusions. Few studies concentrate on interenterprise data open sharing, despite enterprises being crucial to economic operations, directly influencing industry and supply chain development. Open data sharing should involve multiple stakeholders, constituting a complex and dynamic process. Considering that the impact of multiparty participation in data sharing on other entities is crucial, multistakeholder data-sharing games are more practically meaningful than other types of games. Governments serve as guides and motivators, regulating and overseeing societal data open sharing. Thus, this paper adopts a supply chain perspective, integrating the government and supply chain enterprises into a unified analytical framework and leveraging evolutionary game theory to establish a three-party data-sharing game model under government participation. The study aims to explore the pathways through which multiparty involvement in data sharing, seeking to provide theoretical guidance for further open sharing of enterprise data, can be realized.

The marginal contributions of this research are as follows: 1) integrating the government and supply chain enterprises into a unified framework, establishing a tripartite game model between the government and supply chain enterprises, and exploring optimal strategies for data open sharing; 2) incorporating a supply chain perspective, dynamically analyzing the optimal decisions of the government and supply chain enterprises in data open sharing, and breaking away from the constraints of traditional static analysis; 3) offering novel insights to address challenges such as data difficulties and information asymmetry faced during enterprise digital transformation; and 4) enriching the relevant research on open data sharing in supply chain enterprises.

### *1.1. Evolutionary game theory analysis*

Game theory originated in the early 20th century and was cofounded by mathematician John von Neumann and economist Oskar Morgenstern who systematically explored the basic concepts and models of game theory in their book Game Theory and Economic Behavior. Game theory studies the interactive behavior of individuals in a decision-making environment, involving the interests and conflicts of parties under different strategies. After World War II, game theory began to be widely used in economics, social sciences, and other fields, and important theories such as Nash equilibrium emerged [38]. Currently, game theory has become an important interdisciplinary research tool and plays a crucial role in solving practical problems and understanding human behavior [39]. This theory can well explain the game process of data sharing between firms in a fitted supply chain. In this game process, firms are faced with a variety of decisions and actions that are influenced by the costs and benefits of data sharing and government incentives [36].

First, the high and low costs of data sharing among supply chain enterprises are crucial factors. These costs encompass aspects such as data management, the establishment of data security mechanisms, and the cultivation of technical talent [12]. If companies face high costs for data sharing, then their willingness to share data may decline. Second, the digitalization level of enterprises is also a critical factor influencing data sharing. Many enterprises are still at a relatively low level of digital transformation, leading to incomplete and isolated data, as well as compatibility issues between data systems. These problems restrict the effective integration and sharing of data [5].

From the game theory perspective, the decisions made between the manufacturer firm (A) and the downstream firm (B) influence each other. When the manufacturer firm (A) chooses to share data, the downstream firm (B) evaluates its optimal strategy based on this decision. If the benefits from data sharing far outweigh the costs, then the downstream firm (B) may more actively support data sharing [18]. However, if the costs are higher than the number of benefits, then the downstream firm (B) may adopt a relatively conservative attitude or even choose not to actively participate in data sharing [36].

Government incentives can play a guiding role in this game. When firms find that the number of benefits from data sharing is much

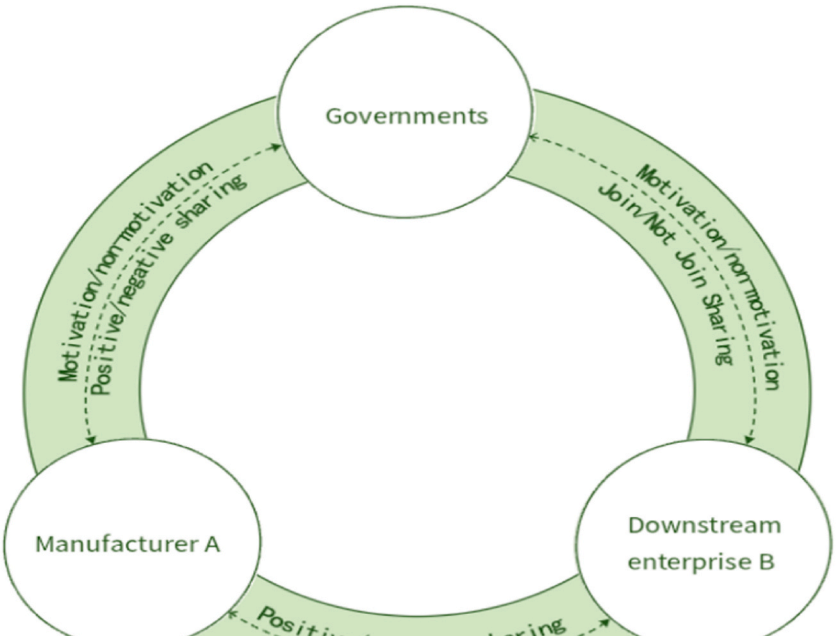


**Fig. 1.** Logic diagram of the relationship among the subjects of the three-party evolutionary game.

lower than the costs, the government can reduce the actual costs faced by firms through subsidies and technical support, thus increasing firms' incentives to participate. This form of government intervention can balance the asymmetry of data sharing to some extent and encourage firms to more actively participate in data sharing [32], thus achieving a larger market size and higher revenue growth levels.

In summary, the gaming process of data sharing among supply chain firms is affected by several factors, including costs, digitization levels, and government incentives [23]. Firms' decisions in the game change according to the interactions among the above factors, and government interventions can, to some extent, guide firms in making decisions that are more favorable for data sharing. This game process can be understood as the process in which supply chain firms seek optimal strategies in the pursuit of larger market shares and degrees of competitive advantage while facing the risks and opportunities of data sharing [35], guided by government policies [14].

Based on the above game theory analysis, the data-sharing system is considered to consist as consisting of the manufacturer (A) and the downstream enterprise (B), where the government acts as the data-sharing incentive party. The constructed relationship diagram of the three-party evolutionary game is shown in Fig. 1.

### *1.2. Case study on data sharing*

A supply chain big-data-sharing and collaboration program has been developed by Jingdong and Midea, which allows data, including inventory, sales, and market trend data, to be shared between the two supply chain companies. Such data sharing allows both parties to more accurately forecast demand, rationally arrange inventory, and optimize replenishment strategies, thereby improving supply chain efficiency and flexibility.

Through data sharing, Jingdong can understand Midea's product demand in a more timely manner, target replenishment, and reduce the risk of inventory backlog. At the same time, Midea can also better grasp the market trend and consumer demand and adjust its production plan and supply chain process to more effectively meet market demand.

This cooperation not only improves the operational efficiency of Jingdong and Midea themselves but also strengthens the partnership between them. By sharing data and information, the two sides have established closer cooperation and achieved more efficient supply chain synergy and collaboration, thus enhancing the operational efficiency and competitiveness of the entire supply chain.

## 2. Model construction and solution

### *2.1. Basic model assumptions*

To construct a three-party game model and explore the strategies of each game subject, the stability of the equilibrium point, and the relationships among the influences of various factors, the following hypotheses are proposed.

**Hypothesis 1**. The government, manufacturer A, and downstream enterprise B serve as participating subjects, and all three parties are assumed to be finite rational subjects.

**Hypothesis 2**. The strategy space for data sharing in the digital transformation process of manufacturer A is (positive sharing, and negative sharing), with x denoting the probability of manufacturer A choosing to share positively; then, 1-x is the probability of manufacturer A choosing to share negatively, and $x \in [0,1]$. The data sharing strategy of the government between manufacturer A and downstream enterprise B is (incentive, disincentive), with z denoting the probability that the government's level of data-sharing between manufacturer A and downstream enterprise B is incentivized; then, 1-z is the probability of the government choosing not to incentivize, $z \in [0,1]$. The strategy space in which downstream enterprise B can perform data-sharing behavior for manufacturer A in the process of digital transformation is (join, do not join). By denoting the probability that downstream enterprise B joins manufacturer A's data sharing with y, 1-y is the probability that downstream enterprise B does not join manufacturer A's data sharing, and $y \in [0,1]$.

**Hypothesis 3**. The benefit gained and cost incurred by manufacturer A from positive sharing are $R_1$, and $C_1$, while the benefit gained and cost incurred by manufacturer A from negative sharing are $R_2$, and $C_2$, respectively. The additional benefit to manufacturer A from downstream firms opting into data sharing is $E_1$, where the benefits to manufacturer A from positive and negative sharing are greater than the costs incurred by positive and negative sharing, respectively.

**Hypothesis 4**. Downstream enterprise B gains benefit $R_3$ and incurs cost $C_3$ by opting into data sharing with manufacturer A and gains no benefit and incurs no cost from not opting into data sharing with manufacturer A. The additional benefit to downstream enterprise B from active data sharing by manufacturer A is $E_4$.

**Hypothesis 5**. The government chooses to incentivize manufacturer A and downstream enterprise B to obtain benefit $R_4$ and incur cost $C_4$; the government chooses not to incentivize manufacturer A and downstream enterprise B, which yields no benefit and incurs no cost. The government incentivizes manufacturer A with a and downstream enterprise B with 1-a, for $a \in [0,1]$. When the government succeeds in incentivizing manufacturer A to openly share its data with downstream enterprise B, the government receives an additional gain, with gain coefficients of $Q_1$ and $Q_2 \in [0,1]$. The gain of the government when manufacturer A actively shares data is $E_2$, while that when downstream enterprise B opts into data sharing is $E_3$.

**Hypothesis 6**. When downstream enterprise B and manufacturer A share data with each other to promote the digitization of the supply chain, it brings about additional value cocreation gains in the supply chain $E_5$ and the allocation coefficients of downstream enterprise B and manufacturer A are 1-m and m, respectively. The government's additional value chain gain coefficient is k. The meaning of specific parameters is shown in Table 1.

### 2.2. Model construction

Based on the above modeling assumptions, the game payoff matrix for the three-party mixed strategy of manufacturer A, downstream enterprise B, and the government can be obtained, as shown in Table 2.

#### 2.2.1. Manufacturer A

From the payoff matrix of the three-party game in Table 2, we can calculate the expected payoff V11 of manufacturer A from choosing a positive data-sharing strategy in the digital transformation process, the expected payoff V12 from choosing a negative data-sharing strategy, and the average expected payoff V1 of manufacturer A in the game, as shown in equations (1a), (1b), and (1c), respectively;

$$V_{11} = zy(R_1 - C_1 + aC_4 + E_1 + E_5m) + (1-z)y(R_1 - C_1 + E_1 + E_5m) + z(1-y)(R_1 - C_1 + aC_4) + (1-z)(1-y)(R_1 - C_1), \quad (1a)$$

$$V_{12} = zy(R_2 - C_2 + aC_4 + E_1) + (1-z)y(R_2 - C_2 + E_1) + z(1-y)(R_2 - C_2 + aC_4) + (1-y)(1-z)(R_2 - C_2), \quad (1b)$$

$$V_1 = xV_{11} + (1-x)V_{12}. \quad (1c)$$

According to the dynamic equation construction method [25], the replicated dynamic equation f(x) for manufacturer A can be constructed as shown in equation (1d) respectively;

$$f_x = -x(x-1)(C_2 - C_1 + R_1 - R_2 + E_5my). \quad (1d)$$

#### 2.2.2. Downstream enterprise B

Similarly, the expected return of downstream enterprise B from opting into data sharing is $V_{21}$, the expected return of downstream enterprise B from not opting into data sharing is $V_{22,}$ and the average expected return is V2, which can be expressed as shown in equations (2a), (2b), and (2c), respectively;

$$V_{21} = xz(R_3 - C_3 + (1-a)C_4 + E_4 + E_5(1-m)) + x(1-z)(R_3 - C_3 + E_4 + E_5(1-m)) + z(1-x)(R_3 - C_3 + (1-a)C_4) + (1-z)(1-x)(R_3 - C_3), \quad (2a)$$

$$V_{22} = xz(E_4 + (1-a)C_4) + x(1-z)E_4 + z(1-x)(1-a)C_4, \quad (2b)$$

$$V_2 = yV_{21} + (1-y)V_{22}. \quad (2c)$$

The replication dynamic equation f(y) for downstream enterprise B is constructed as shown in equation (2d) respectively;

$$f_y = y(y-1)(C_3 - R_3 - E_5x + E_5mx). \quad (2d)$$

#### 2.2.3. Government

Similarly, the expected return from the government incentivization of shared data is V31, the expected return from the government nonincentivization of shared data is V32 and the average expected return V3 are as shown in equations (3a), (3b), and (3c),

**Table 1**
Model parameters and meanings.

| Variable | Meaning |
|---|---|
| $R_1$ | Manufacturer A's Benefits from Active Data Sharing |
| $R_2$ | Manufacturer A's Benefits from Passive Data Sharing |
| $R_3$ | Enterprise B's Benefits from Joining Data Sharing |
| $R_4$ | Government's Benefits from Incentivizing Data Sharing |
| $C_1$ | The Costs Incurred by Manufacturer A from Active Data Sharing |
| $C_2$ | Costs Incurred by Manufacturer A from Passive Data Sharing |
| $C_3$ | Costs Incurred by Enterprise B from Joining Data Sharing |
| $C_4$ | Costs Incurred by the Government from Incentivizing Data Sharing |
| $E_1$ | Additional Gains for Downstream Enterprise B from Sharing Data Sharing with Manufacturer |
| $E_2$ | Additional Gains for Manufacturer A from Sharing Data with the Government |
| $E_3$ | Additional Gains for Downstream Enterprise B from Sharing Data with and Bringing Additional Benefits to the Government |
| $E_4$ | Additional Gains for Manufacturer A from Actively Sharing Data with Downstream Enterprise B |
| $E_5$ | Additional Supply Chain Benefits from Actively Sharing Data among Supply Chain Enterprises |
| $Q_1$ | Coefficient of Additional Gains for the Government from Manufacturer A's Data Sharing |
| $Q_2$ | Coefficient of Additional Gains for the Government from Downstream Enterprise B's Data Sharing |
| M | Coefficient of Value Cocreation Benefit Allocation among Supply Chain Entities |
| a | Coefficient of Government Incentive Intensity |

**Table 2**
Game payoff matrix for manufacturer A, downstream enterprise B, and the government in a three-way mixed strategy.

| Three-party game payoff matrix | | | |
|---|---|---|---|
| Strategic choice | Manufacturer A | Downstream Enterprise B | Government |
| I(1,1,1) | $R_1–C_1+aC_4+E_1+E_5m$ | $R_3–C_3+(1-a)C_4+E_4+E_5(1-m)$ | $R_4(1+Q_1+Q_2)-C_4+E_2+E_3+kE_5$ |
| II(1,1,0) | $R_1–C_1+E_1+E_5m$ | $R_3–C_3+e_4+E_5(1-m)$ | $E_2+E_3+kE_5$ |
| III(1,0,1) | $R_1–C_1+aC_4$ | $E_4+(1-a)C_4$ | $R_4(1+Q_1)-C_4+E_2$ |
| IV(1,0,0) | $R_1–C_1$ | $E_4$ | $E_2$ |
| V(0,1,1) | $R_2–C_2+aC_4+E_1$ | $R_3–C_3+(1-a)C_4$ | $R_4(1+Q_2)-C_4+E_3$ |
| VI(0,1,0) | $R_2–C_2+E_1$ | $R_3–C_3$ | $E_3$ |
| VII(0,0,1) | $R_2–C_2+aC_4$ | $(1-a)C_4$ | $R_4–C_4$ |
| VIII(0,0,0) | $R_2–C_2$ | 0 | 0 |

respectively;

$$V_{31} = xy(R_4(1+Q_1+Q_2) - C_4 + E_2 + E_3 + kE_5) + x(1-y)(R_4(1+Q_1) - C_4$$

$$+E_2) + (1-x)y(R_4(1+Q_2) - C_4 + E_3) + (1-y)(1-x)(R_4 - C_4), \tag{3a}$$

$$V_{32} = xy(E_2 + E_3 + kE_5) + x(1-y)E_2 + (1-x)yE_3, \tag{3b}$$

$$V_3 = zV_{31} + (1-z)V_{32}. \tag{3c}$$

The government's replication dynamic equation f(z) is constructed as shown in equation (3d) respectively;

$$f_z = -z(z-1)(-R_4 - C_4 + Q_1R_4x + Q_2R_4y). \tag{3d}$$

## 3. Model analysis

### 3.1. Manufacturer A

According to the evolutionary game and stability theorem of differential equations, it can be seen that the probability of manufacturer A choosing to share data during digital transformation is in a steady state, which must be realized as follows: $f(x) = 0, \frac{d(f(x))}{dx} < 0$.

The first-order derivative of x is identified, and g(y) is set as shown in equations (4)–(6), respectively;

$$\frac{d(f(x))}{dx} = (1-2x)(C_2 - C_1 + R_1 - R_2 + myE_5), \tag{4}$$

$$g(y) = C_2 - C_1 + R_1 - R_2 + myE_5, \tag{5}$$

$$y' = \frac{C_1 - C_2 + R_2 - R_1}{mE_5}. \tag{6}$$

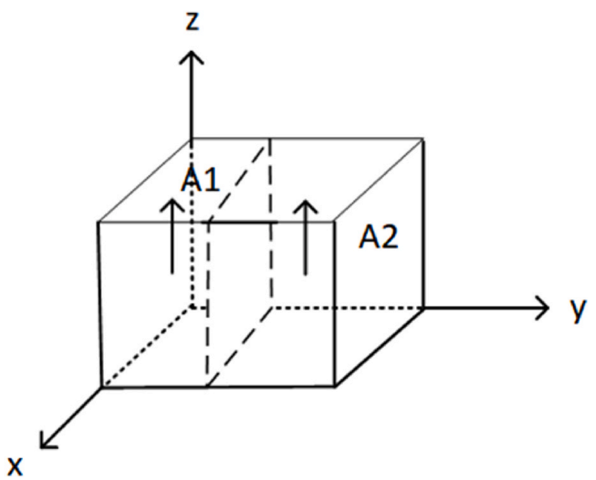


**Fig. 2.** Phase diagram of the evolution of manufacturer A's data-sharing strategy.

Since $\frac{d(g(y))}{dy} = mE_5 > 0$, g(y) is an increasing function when $y = y'$, $g(y) = 0$, $f(x) = 0$, and $\frac{d(f(x))}{dx} = 0$, and the manufacturer is unable to determine the stabilizing strategy when $y < y'$, $g(y) < 0$, $\frac{d(f(x))}{dx}|_{x=0} < 0$, and $x = 0$ is the evolutionary stable strategy of manufacturer A. Similarly, $g(y) > 0$, $\frac{d(f(x))}{dx}|_{x=1} < 0$, and $x = 1$ is the evolutionary stable strategy of manufacturer A when $y > y'$ The evolutionary phase diagram of the manufacturer's strategy is shown in Fig. 2.

Fig. 2 shows that the probabilities of manufacturer A positively and negatively sharing data are calculated as volume $V_{A2}$ of A2 and volume $V_{A1}$ of A1, as shown in equation (7), and (8), respectively;

$$V_{A1} = \int_0^1 \int_0^1 \frac{C_1 - C_2 + R_2 - R_1}{mE_5} dzdx = \frac{C_1 - C_2 + R_2 - R_1}{mE_5}, \tag{7}$$

$$V_{A2} = 1 - V_{A1} = \frac{mE_5 - C_1 + C_2 - R_2 + R_1}{mE_5}. \tag{8}$$

**Corollary 1**. *As m, $E_5$, $C_2$, and $R_1$ gradually increase, manufacturer A becomes more inclined to choose to positively share digital transformation data, but as $R_2$ and C1 gradually increase, manufacturer A is inclined to choose to negatively share data. In other words, the probability of manufacturer A choosing to share transformation data is positively correlated with the strength of the government's incentives for manufacturer A to share its data, the gains achieved by manufacturer A's positive sharing of its data, and the costs incurred by manufacturer A's negative sharing of its data. The costs incurred by manufacturer A's negative data sharing are positively proportional to the gains obtained by manufacturer A's negative open sharing of data. The costs incurred by manufacturer A's positive data sharing are negatively correlated.*

ProofTake the first-order partial derivatives of $\frac{dVA2}{dm} > 0$, $\frac{dVA2}{dE5} > 0$, $\frac{dVA2}{dc1} < 0$, $\frac{dVA2}{dc2} > 0$, and $\frac{dVA2}{dR_1} > 0$; thus, the probability of manufacturer A choosing to positively share its data increases with increasing m, $E_5$, $C_2$, and $R_1$ values.

### 3.2. Downstream enterprise B

According to the evolutionary game and stability theorem of the differential equation, it can be seen that the probability of downstream enterprise B choosing to opt into data-sharing is in a stable state that must be realized as follows: $f(y) = 0$, and $\frac{d(f(y))}{dy} < 0$.

The first-order derivative of y and set g(x) are as shown in equations (9)–(11), respectively;

$$\frac{d(f(y))}{dy} = (2y - 1)(C_3 - R_3 - E_5 x + mxE_5), \tag{9}$$

$$g(x) = C_3 - R_3 - E_5 x + mxE_5, \tag{10}$$

$$x' = \frac{C_3 - R_3}{(1 - m)E_5}. \tag{11}$$

Because $\frac{d(g(x))}{dx} = (m - 1)E_5 < 0$, g(x) is a decreasing function; when x = x', $g(x) = 0$, $f(y) = 0$, and $\frac{d(f(y))}{dy} = 0$, downstream enterprise

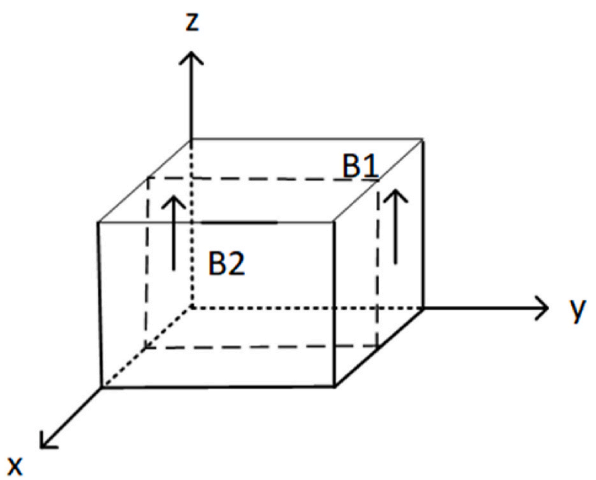


**Fig. 3.** Phase diagram of the evolution of downstream enterprise B's strategies.

B cannot determine the stabilization strategy. When $x < x'$, $g(x) > 0$, $\frac{d(f(y))}{dy}|_{y=0} < 0$, and $y = 0$ denote the evolutionary stabilizing strategy of downstream enterprise B. Similarly, $g(x) < 0$, $\frac{d(f(y))}{dy}|_{y=1} < 0$, and $y = 1$, denote the evolutionary stabilizing strategy of downstream enterprise B when $x > x'$. The phase diagram of the strategy evolution of downstream enterprise B is shown in Fig. 3.

Fig. 3 shows that the probabilities of downstream enterprise B opting into and not opting into data sharing are the volume $V_{B2}$ of B2, and volume $V_{B1}$ of B1, respectively. These two factors are calculated as shown in equation (12) and (13), respectively;

$$V_{B1} = \int_0^1 \int_0^1 \frac{C_3 - R_3}{(1-m)E_5} dz dy = \frac{C_3 - R_3}{(1-m)E_5}, \tag{12}$$

$$V_{B2} = 1 - V_{B1} = \frac{(1-m)E_5 - C_3 + R_3}{(1-m)E_5}. \tag{13}$$

Inference 2: As $E_5$ and $R_3$ gradually increase, downstream enterprise B becomes more inclined to choose to opt into data sharing, but as m and $C_3$ gradually increase, downstream enterprise B is inclined to choose to not opt into data sharing; i.e., the probability of downstream enterprise B choosing the strategy of opting into data sharing is positively proportional to the gains achieved by downstream enterprise B through such joining and to the additional value generated by the value cocreation of the supply chain and inversely proportional to the distribution coefficients of the costs paid by downstream enterprises B. The distribution coefficient of the cost faced by downstream enterprise B in opting into data sharing and the value cocreation gain from the digitization of the supply chain between downstream enterprise B and manufacturer A is inversely proportional to the cost faced by downstream enterprise B by opting into data-sharing and the value cocreation gain from the digitization of the supply chain between downstream enterprise B and manufacturer A.

Proof: The first-order partial derivatives for each element of VB2 are $\frac{dVB2}{dm} < 0$, $\frac{dVB2}{dE5} > 0$, $\frac{dVB2}{dC3} < 0$, and $\frac{dVB2}{dR3} > 0$. Therefore, as $E_5$ and $R_3$ increase, the probability of downstream enterprise B opting into data sharing increases.

### 3.3. Government

According to the stability theorem of the evolutionary game and differential equations, it can be seen that the probability of the government choosing data-sharing is in a stable state and must be realized as follows: $f(z) = 0$, and $\frac{d(f(z))}{dz} < 0$.

The first-order derivative of z and set function $h(y)$ are as shown in equation (13), (14), and (15), respectively;

$$\frac{d(f(z))}{dz} = (1-2z)\left((R_4 - C_4 + xQ_1R_4 + Q_2R_4y),\right. \tag{13}$$

$$h(y) = R_4 - C_4 + xQ_1R_4 + Q_2R_4y, \tag{14}$$

$$y' = \frac{C_4 - R_4 - Q_1R_4X}{Q_2R4}. \tag{15}$$

*Since* $\frac{d(h(y))}{dy} = Q_2R_4 > 0$, $h(y)$ is an increasing function when $y = y'$ $h(y) = 0, f(z) = 0$, and $\frac{d(f(z))}{dz} = 0$ and the government is unable to determine the stabilizing strategy when $y < y'$, $h(y) < 0$, $\frac{d(f(z))}{dz}|_{z=0} < 0$, and $z = 0$ denote the evolutionary stabilization strategy of

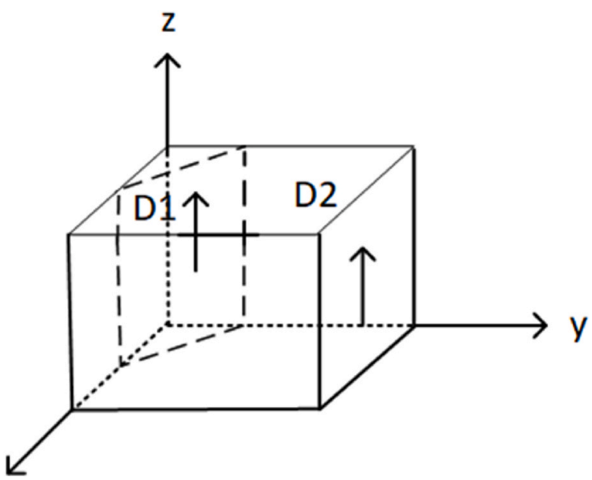


**Fig. 4.** Phase diagram of the government's strategy evolution.

manufacturer A. Similarly, when $y > y^{'}, h(y) > 0, \frac{d(f(z))}{dz}|_{z=1} < 0$, and $z = 1$ denote the evolutionary stabilization strategy of the government. The evolutionary phase diagram of the government's strategy is shown in Fig. 4.

Fig. 4 shows that the probabilities of the government choosing an incentivized strategy and disincentivized strategy are the volume $V_{D1}$ of D2 and volume $V_{D2}$ of D2, which are calculated as shown in equation (16), and (17), respectively;

$$V_{D1} = \int_0^1 \int_0^1 \left( \frac{C_4 - R_4 - Q_1 R_4 x}{Q_2 2R_4} \right) dxdz = \frac{2C_4 - 2R_4 - Q_1 R_4}{2Q_2 R_4}, \tag{16}$$

$$V_{D2} = 1 - V_{D1} = \frac{2Q_2 R_4 - 2C_4 + 2R_4 + Q_1 R_4}{2Q_2 R_4}. \tag{17}$$

Inference 3: As $Q_1$, $Q_2$, and $R_4$ gradually increase, the government becomes more inclined to choose the incentive strategy, but as $C_4$ gradually increases, the government is inclined to choose the non-incentive strategy; i.e., the probability of the government choosing the incentive strategy is positively correlated with the gains obtained by the government through its incentive strategy, and the coefficient of the gains of the government's success in the open sharing of enterprise data is negatively correlated with the costs incurred by the government from adopting the incentive strategy.

Proof: Find the first-order partial derivatives for each element of $V_{D2}$. $\frac{dVD2}{dC4} < 0, \frac{dVD2}{dQ1} > 0, \frac{dVD2}{dR4} > 0, and \ \frac{dVD2}{dQ2} > 0$. Therefore, as $Q_1$, $Q_2$, and $R_4$ increase, the probability of the government choosing an incentive data-sharing strategy increases.

### 3.4. Stabilization strategy solving

Let $f(x) = 0$, $f(y) = 0$, and $f(z) = 0$ to obtain 10 local equilibrium points, namely, E1(0,0,0), E2(1,0,0), E3(0,1,0), E4(0,0,1), E5 (1,1,0), E6(1,0,1), E7(0,1,1), E8(1,1,1), E9(($C_3$–$R_3$)/($E_5$-$E_5$m), ($C_1$–$C_2$-$R_1$+$R_2$)/($E_5$m),0), E10(($C_3$–$R_3$)/($E_5$-$E_5$m), ($C_1$–$C_2$-$R_1$+$R_2$)/ ($E_5$m),1). Based on the replicated dynamic equations of manufacturer A, downstream enterprise B, and the government, i.e., based on equations (4)–(6), we derive the Jacobian matrix, equation (7), and carry out a localized equilibrium point of system stability analysis as shown in equation (18) respectively;

$$A = \begin{cases} [-(x-1)(C_2 - C_1 + R_1 - R_2 + E_5 my) - x(C_2 - C_1 + R_1 - R_2 + E_5 my), -E_5 mx(x-1), 0] \\ [-y(y-1)(E_5 - E_5 m), y(C_3 - R_3 - E_5 x + E_5 mx) + (y-1)(C_3 - R_3 - E_5 x + E_5 mx), 0] \\ [-Q_1 R_4 z(z-1), -Q_2 R_4 z(z-1), -z(R_4 - C_4 + Q_1 R_4 x + Q_2 R_4 y) R_4 - C_4 + Q_1 R_4 x + Q_2 R_4 - (z-1)(R_4 - C_4 \\ +Q_1 R_4 x + Q_2 R_4 y) R_4 - C_4 + Q_1 R_4 x + Q_2 R_4 y) \end{cases}. \tag{18}$$

The equilibrium point E1(0,0,0) is first analyzed and brought into the Jacobian matrix (18), which, at this point, is as shown in equation (19) respectively;

$$B = \begin{pmatrix} C_2 - C_1 + R_1 - R_2 & 0 & 0 \\ 0 & R_3 - C_3 & 0 \\ 0 & 0 & R_3 - C_3 \end{pmatrix}. \tag{19}$$

The eigenvalues of the Jacobian matrix for the equilibrium point E1(0,0,0) are $\lambda_1 = C_2 - C_1 + R_1 - R_2, \lambda_2 = C_2 - R_3 - C_3, \lambda_3 = R_4 - C_4$. The eigenvalues of the Jacobian matrix corresponding to the equilibrium points can be obtained by adding the above-mentioned 10 equilibrium points into Jacobian matrix (7).

After utilizing the first Lyapunov method, all eigenvalues of the Jacobian matrix are shown to have negative real parts, the equilibrium point is asymptotically stable; at least one of the eigenvalues of the Jacobian matrix is shown to have a positive real part, and the equilibrium point is unstable; the eigenvalues of the Jacobian matrix, except for those with a real part of zero, are shown to

**Table 3**
Stability of equalization points.

| Balance point | Eigenvalue (math.)1 | Eigenvalue (math.)2 | Eigenvalue (math.)3 | Stability conclusions |
|---|---|---|---|---|
| E1(0,0,0) | $R_3$–$C_3$ | $R_4$–$C_4$ | $C_2$–$C_1$ + $R_1$–$R_2$ | Non-ESS |
| E2(1,0,0) | $R_4$–$C_4$ + $Q_1R_4$ | $C_1$–$C_2$ - $R_1$ + $R_2$ | $R_3$–$C_3$ + $E_5$ - $E_5$m | Non-ESS |
| E3(0,1,0) | $C_3$–$R_3$ | $R_4$–$C_4$ + $Q_2R_4$ | $C_2$–$C_1$ + $R_1$–$R_2$ + $E_5$m | Non-ESS |
| E4(0,0,1) | $R_3$–$C_3$ | $C_4$–$R_4$ | $C_2$–$C_1$ + $R_1$–$R_2$ | Non-ESS |
| E5(1,1,0) | $C_3$–$R_3$ - $E_5$ + $E_5$m | $R_4$–$C_4$ + $Q_1R_4$ + $Q_2R_4$ | $C_1$–$C_2$ - $R_1$ + $R_2$ - $E_5$m | Non-ESS |
| E6(1,0,1) | $C_4$–$R_4$ - $Q_1R_4$ | $C_1$–$C_2$ - $R_1$ + $R_2$ | $R_3$–$C_3$ + $E_5$ - $E_5$m | Non-ESS |
| E7(0,1,1) | $C_3$–$R_3$ | $C_4$–$R_4$ - $Q_2R_4$ | $C_2$–$C_1$ + $R_1$–$R_2$ + $E_5$m | Non-ESS |
| E8(1,1,1) | $C_3$–$R_3$ - $E_5$+$E_5$m | $C_4$–$R_4$ - $Q_1R_4$ - $Q_2R_4$ | $C_1$–$C_2$ - $R_1$ + $R_2$ - $E_5$m | ESS |
| E9(($C_3$–$R_3$)/($E_5$-$E_5$m),($C_1$–$C_2$-$R_1$+$R_2$)/($E_5$m),0) | β | α | -β | \\\ |
| E10(($C_3$–$R_3$)/($E_5$-$E_5$m),($C_1$–$C_2$-$R_1$+$R_2$)/($E_5$m),1) | β | -β | -α | \\ |

Note that β=(m($C_3$–$R_3$)(m - 1)($C_1$–$C_2$ - $R_1$ + $R_2$)($C_3$–$R_3$ - $E_5$ + $E_5$m)($C_2$–$C_1$ + $R_1$–$R_2$ +$E_5$m))^(1/2)/(-$E_5$m^2 + $E_5$m) and that α = ($C_1Q_2R_4$–$C_2Q_2R_4$ - $Q_2R_1R_4$ + $Q_2R_2R_4$–$C_4E_5$m + $R_4E_5$m + $C_4E_5$m^2 - $R_4E_5$m^2 - $C_1Q_2R_4$m + $C_2Q_2R_4$m + $C_3Q_1R_4$m + $Q_2R_1R_4$m - $Q_1R_3R_4$m - $Q_2R_2R_4$m)/(-$E_5$m^2 + $E_5$m).

have negative real parts, and the equilibrium point is in a critical state; and the stability is shown to not be able to be determined by the sign of the eigenvalues. The stability of each equilibrium point is analyzed, as shown in Table 3.

**Corollary 4**. *When* $C_1$–$C_2$ - $R_1$ + $R_2$ - $E_5m < 0$, *there exists only one stabilization point*, E8(1,1,1), *for the system of replicated dynamic equations*.

Proof: When $C_1$–$C_2$ - $R_1$ + $R_2$ -$E_5$m < 0, E7(0,1,0) is unstable and because $R_1$–$C_1$>0 and $R_2$–$C_2$>0, E9(($C_3$–$R_3$)/($E_5$-$E_5$m),($C_1$–$C_2$-$R_1$+$R_2$)/($E_5$m),0) and E10(($C_3$–$R_3$)/($E_5$-$E_5$m),($C_1$–$C_2$-$R_1$+$R_2$)/($E_5$m),1) are meaningless, and E1(0,0,0), E2(1,0,0), E3(0,1,0), E4 (0,0,1), E5(1,1,0), and E6(1,0,1) are unstable points.

Corollary 4 shows that manufacturers obtain a higher number of benefits from positive data sharing and a lower number of benefits from negative sharing when they digitally transform. The government incentivizes manufacturer A and downstream enterprise B, and downstream enterprise B opts into data sharing at a lower cost. Moreover, when a higher number of benefits are brought about by opting into data sharing, the only stable equilibrium can be identified; i.e., when manufacturer A shares its data positively, downstream enterprise B opts into data sharing, and the government incentivizes both firms to share their data.

## 4. Simulation analysis

### *4.1. Impact of data sharing costs and benefits on supply chain enterprises*

To verify the accuracy and validity of the evolutionary game, this paper combines the actual situation with the reasonable assignment of the model using MATLAB 2023a for numerical simulation. Data set 1: $R_1 = 100$, $R_2 = 70$, $R_3 = 80$, $R_4 = 60$, $C_1 = 25$, $C_2 = 15$, $C_3 = 20$, $C_4 = 40$, $E_1 = 30$, $E_2 = 20$, $E_3 = 15$, $E_4 = 20$, $E_5 = 40$, $Q_1 = 0.2$, $Q_2 = 0.1$, m = 0.6, a = 0.6, and k = 0.3; this dataset meets the condition of Corollary 4 and is used to explore the effects of $R_1$, $R_2$, $R_3$, $C_1$, $C_2$, $C_3$, $C_4$, and $E_5$ on the evolutionary game process and outcome.

First, we analyze the degree of influence of the change in positive data-sharing gain $R_1$ and negative data-sharing gain $R_2$ of manufacturer A on the whole evolution process and outcome, setting $R_1$ to $R_1 = 100$, 130, and 180 and replicating the simulation results of the dynamic equation system evolving with the change in R1 50 times, as shown in Fig. 5. Then, we set $R_2$ to $R_2 = 70$, 110, and 150 and replicate the results of the system of dynamic equations evolving with R2 changes 50 times, as shown in Fig. 6.

As seen in Fig. 5, in the process of the replication dynamic equation system evolving into a stable point, the accompanying increase in the gains from the positive sharing of digital transformation data of manufacturer A can promote the evolutionary progress of its choice of the positive data-sharing strategy. With the increasing positive sharing gain R1, manufacturer A tends to choose the strategy of positive data-sharing, while the probabilities of the government choosing the strategy of not incentivizing and of the downstream enterprises B choosing that of not opting into data sharing are increasing. Therefore, an appropriate increase in the benefit R1 of positive data sharing by manufacturer A helps the manufacturer decide to choose the positive data sharing strategy.

Fig. 6 shows that in the process of replicating the evolution of the dynamic system of equations, along with the enhancement of $R_2$, the probability of manufacturer A choosing a negative data-sharing strategy greatly increases, while the probability of downstream enterprise B choosing to opt into data sharing and the government choosing an incentive strategy become more obvious. This finding indicates that the government and downstream enterprise B choose opposite strategies to incentivize the promotion of manufacturer A's active sharing of digital transformation data when manufacturer A chooses the negative data-sharing strategy.

Next, a further discussion focuses on how the changes in the benefits (R3) from downstream enterprises B joining in on data sharing affect the process and outcome of the evolutionary game. Based on the original set of assignments, the setting of $R_3$ to $R_3 = 80$, 120, and 160 for simulation purposes allows us to obtain the results in Fig. 7.

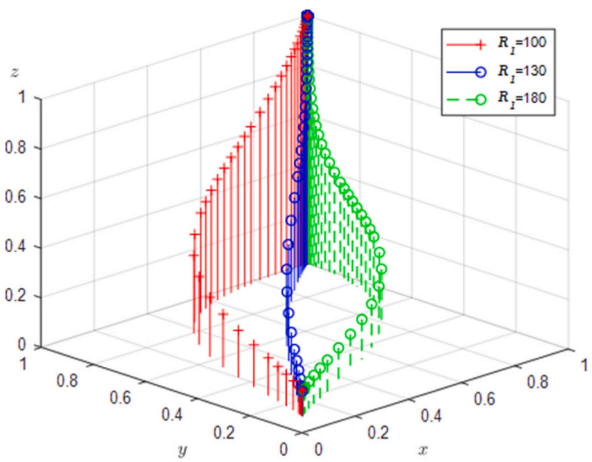


**Fig. 5.** Impact of manufacturer A's gains from positive Sharing.

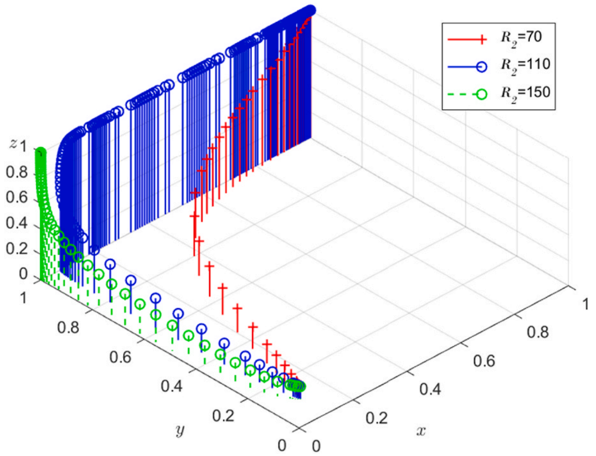


**Fig. 6.** Impact of manufacturer A's gains from negative sharing.

From Fig. 7, it can be seen that as downstream enterprise B opts into data sharing, R3 increases, downstream enterprise B increasingly tends to opt into data sharing, and the speed of evolution also accelerates. As downstream enterprise B opts into data sharing, its number of benefits increases and its tendency to choose government incentives, both of which are situations that are more consistent with reality. There are benefits of a low number of government incentives in promoting downstream enterprise B opting into data sharing, but as the number of benefits of R3 continues to rise, the enormous number of benefits will drive downstream enterprise B to spontaneously choose the data-sharing strategy.

Furthermore, the effects of the downstream firm's cost of opting into data-sharing $C_3$ and the cost of actively sharing data by manufacturer A $C_1$ on the evolutionary stability of the replicated dynamic equation system are again explored. The value of $C_1$ is set to $C_1 = 25$, 35, and 50 for the simulation to obtain Fig. 8, and then, the value of $C_3$ is set to $C_3 = 20$, 30, and 40 for the simulation to obtain the result in Fig. 9.

As seen from Fig. 10, as the cost of sharing data rises for manufacturer A, it will be more inclined to share data negatively. The rate of evolution to stability decreases, while the presence of government incentives and the downstream enterprise's willingness to opt into data-sharing increase, and the government and downstream enterprise further increase the probability of manufacturer A choosing to positively share data through incentive and data-sharing strategies.

Fig. 9 shows that as the cost of opting into data sharing increases for downstream enterprise B, the probabilities of there being government incentives and manufacturer A choosing these incentives and active data sharing, increase. The government encourages downstream enterprise B to opt into data sharing through incentive strategies such as subsidies and technical guidance, while manufacturer A further promotes the choice of the data-sharing strategy by downstream enterprise B by actively opening up the shared data. Furthermore, the appropriate levels of government incentives and manufacturer A's active sharing of data incentivize downstream enterprises B to choose the data-sharing strategy.

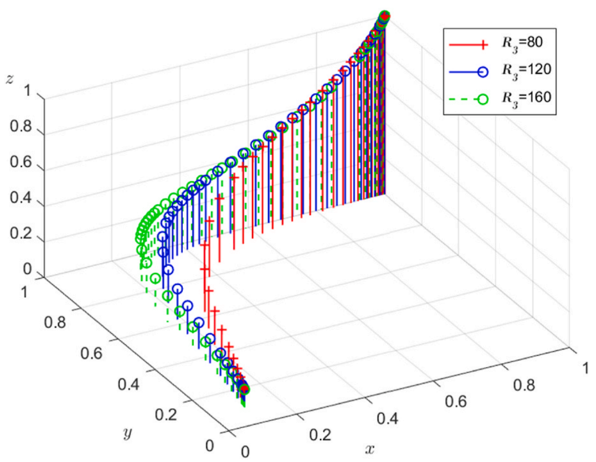


**Fig. 7.** Impact of the benefits of downstream enterprise B opting into data sharing.

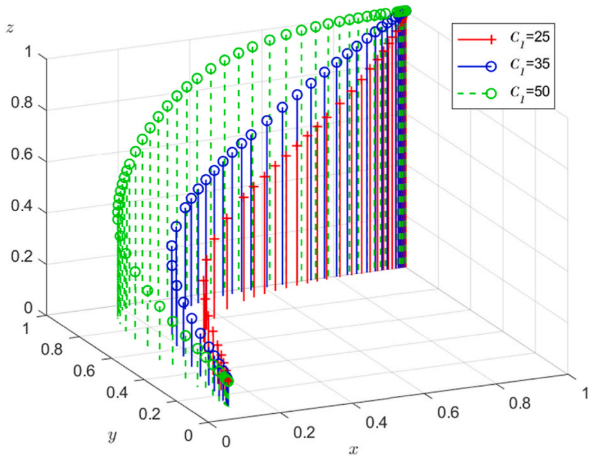


**Fig. 8.** Impact of manufacturer A's active data-sharing costs.

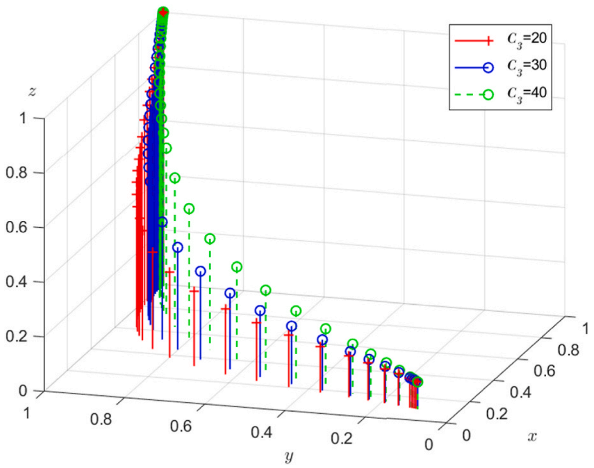


**Fig. 9.** Impact of the cost of data-sharing accession by downstream enterprise B.

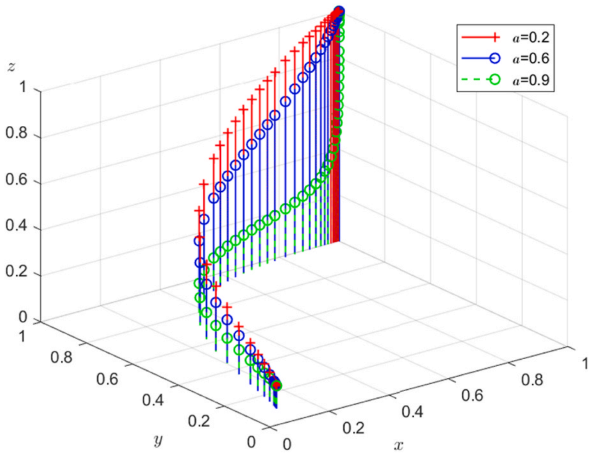


**Fig. 10.** Impact of the strength of the government's incentive on manufacturer A and downstream enterprise B.

### 4.2. Impact of government incentives on data sharing among supply chain enterprises

How the variations in the government's incentive intensity (C4) for data sharing affect the evolution and outcomes of data-sharing games among supply chain enterprises is discussed. Based on the original assigned values, simulation results are obtained after assigning values of a = 0.2, 0.6, and 0.9, resulting in Fig. 10.

Fig. 8 shows that as the cost of government incentives continues to rise, the probability of the government choosing the incentive strategy decreases, the evolution rate to the stabilization point also decreases, and the probability of downstream enterprise B and manufacturer A choosing to opt into data-sharing and positive data-sharing strategies, respectively, is increasing, indicating that with the increase in the level of government incentives, manufacturer A and downstream enterprise B become increasingly inclined to choose positive data-sharing and thus the data-sharing strategy.

### 4.3. Impact of supply chain value cocreation on enterprise data openness

Finally, the effect of supply chain data sharing brought about by the downstream enterprise B opting into the data sharing of manufacturer A, thereby realizing the supply chain value cocreation gain $E_5$, on the evolutionary stability of the replicated dynamic equation system is then explored. The value of $E_5$ is set to $E_5 = 40$, 50, and 70 for simulation purposes to obtain Fig. 11.

From Fig. 11, it can be seen that with the increasing supply chain value cocreation gain E5, the driving effect on the downstream enterprise B is stronger than that of manufacturer A, and downstream enterprise B has a stronger willingness to promote supply chain data-sharing than does manufacturer A. At the same time, with the increasing number of benefits from supply chain value cocreation, the government is more willing to incentivize supply chain enterprises' data-sharing as a way of incentivizing both manufacturer A and downstream enterprise B. The results show that the government is more willing to incentivize data-sharing between manufacturer A and downstream enterprise B than it is other data-sharing structures. The results suggest that the increase in the number of supply chain value creation benefits associated with data sharing between manufacturer A and downstream enterprise B significantly promotes active data sharing between the two parties. The results also suggest that the government is more willing to incentivize data sharing between manufacturer A and downstream enterprise B as the number of supply chain value creation benefits increases.

### 4.4. Analysis of the evolutionary results of 50 iterations of data sharing games

The initial dataset meets the conditions in Corollary 4 and evolves through different strategy combinations over 50 simulations, as shown in Fig. 12. Moreover, as seen in Fig. 12, there is only one stable equilibrium point, E(1,1,1), obtained from the simulation results, and there exists only one combination of evolutionarily stable strategies (active sharing, joint sharing, and incentivizing). Thus, manufacturer A actively shares its data, downstream enterprise B enters into data sharing, and the government provides incentives. The incentive combination strategy contributes to the data-sharing effect of supply chain enterprises and helps promote the value cocreation and digital transformation of the supply chain. Furthermore, the simulation results are consistent with the conclusions of the stability analysis and exhibit validity, which is of guiding significance for data sharing among enterprises in the supply chain.

## 5. Conclusions, recommendations, and prospects for future research

### 5.1. Main conclusions

(1) Manufacturer A's willingness to actively share transformational data is influenced by the benefits of its active data sharing, the magnitude of its costs, and the extent of government incentives for supply chain firms to share data. The number of benefits from supply chain value cocreation has a positive impact on manufacturer A's choice of the active data-sharing strategy. As the level of government incentives deepens, the number of benefits from data-sharing rises, and the cost of data sharing declines, which both incentivize Manufacturer A to choose an active data-sharing strategy.

(2) Downstream enterprise B's behavior of choosing to share its data is positively influenced by the benefits obtained through supply chain value cocreation, the benefits of downstream enterprise B opting into data sharing, and the degree of government incentives. Moreover, as the cost of actively sharing data increases for manufacturer A, the probability of downstream enterprise B opting into data sharing increases. The increase in the cost of data sharing indicates a simultaneous increase in the level of effort and costs faced by firms for data sharing. Effective government incentives, along with the increase in the benefits from opting into data sharing and the increase in the benefits of supply chain value cocreation, can motivate downstream enterprise B to choose to adopt the data-sharing strategy.

(3) Whether the government chooses to incentivize supply chain enterprises to share their data is affected by the benefits and costs faced by supply chain enterprises when sharing data. In addition, data sharing by the supply chain enterprise will bring about value cocreation and the amount of additional revenue affects the government's choice of strategy. The probability of the government choosing to offer incentives is negatively correlated with supply chain enterprises' data-sharing benefits and positively correlated with supply chain enterprises' data-sharing costs and the additional benefits from supply chain value cocreation. The increase in the number of supply chain value cocreation benefits from data sharing will drive the government to choose incentive data-sharing strategies. If the cost of data sharing is too high, then the government also chooses to increase the degree of incentives it offers to supply chain enterprises to encourage them to openly share their data.

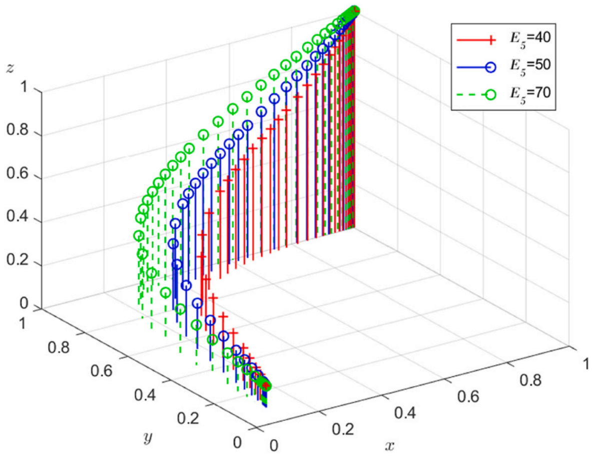


**Fig. 11.** Impact of supply chain data-sharing value cocreation benefits.

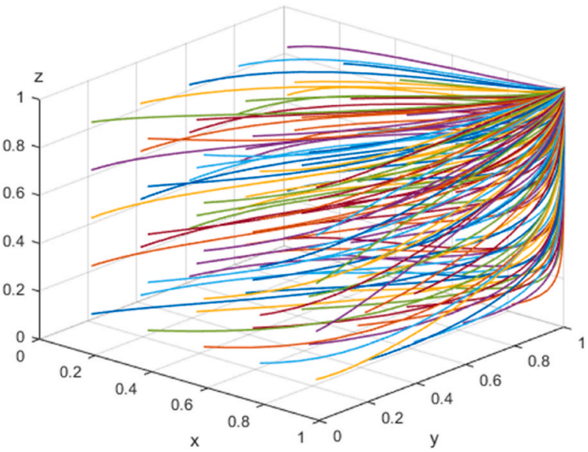


**Fig. 12.** Results of evolving array 1, 50 times.

(4) Data sharing among supply chain firms optimizes the decision-making process and resource allocation and improves operational efficiency. Data sharing allows for better forecasting, inventory management, and risk mitigation strategies. In addition, data sharing facilitates collaboration among supply chain partners, increasing the degree of transparency and trust and making operations more rational. Such collaboration tends to make the supply chain more synchronized and responsive, which ultimately benefits the overall management and performance of the companies involved and achieves value cocreation among supply chain enterprises, which in turn incentivizes corporate data sharing.

### 5.2. Recommendations

According to the above relevant research conclusions, to further promote open data-sharing among enterprises and achieve enterprise digital transformation in the face of a lack of data resources, data silos, and other challenges, this paper proposes relevant recommendations from the perspective of supply chain enterprises and the government.

(1) Deepen the awareness of enterprise data sharing, and strengthen the ability of enterprises to share their data.

The training of enterprise personnel in data-sharing capacity should be strengthened. The difficulty of insufficient capacity faced by enterprises in data sharing should be solved, and second, the data-sharing process of supply chain enterprises should be optimized. Unified data standards and data interfaces should be developed, and the expenditure of data-sharing costs should be reduced. At the same time, the management and construction of data resources within the enterprise should be enhanced, the utilization rate of data resources should be improved, and information fragmentation and repeated collection should be avoided. The dimension and depth of data should be increased, internal collaboration and innovation should be promoted, the complementarity of data among supply chain enterprises should be enhanced, a database of supply chain enterprises should be built, and a guarantee mechanism for enterprise data sharing should be established.

(2) Increase the degree of government data-sharing incentives

The government provides subsidy incentives to encourage active data sharing among supply chain enterprises, supplementing regulatory norms and adjusting corresponding government incentive policies based on the conditions of the enterprises to increase the benefits of data sharing within the supply chain. This approach helps alleviate the financial challenges associated with data sharing, easing the burden of data-sharing costs for enterprises, and encouraging open data-sharing practices. Consequently, this approach further unlocks the potential of data sharing.

### *5.3. Prospects for future research*

With the development of supply chain management, the game of data sharing among enterprises will continue to be a topic of great interest. Future research can continue to focus on data security and privacy protection, and researchers need to explore more effective data encryption and secure sharing mechanisms to cope with issues such as data leakage and privacy invasion. A more in-depth study of cooperation and competition in data sharing among enterprises should be performed. How to achieve cooperation in competition and jointly promote supply chain efficiency and at the same time promote: the establishment of a perfect data-sharing system and standards and provide a more standardized and convenient way for interenterprise data exchange should also be identified. This requires the joint efforts of the government, enterprises, and academia to promote standardization and normative development within the industry.

The existing game model in this study may be simplified in describing the data sharing of real supply chain enterprises, ignoring the influence of irrational factors, and future research needs to develop a more complex model that is closer to the actual model. Second, this study may be limited to a certain extent to specific perspectives and dimensions, and future studies may try to explore the mechanisms and factors influencing supply chain data sharing from multiple perspectives and levels. Subsequent studies can develop more complex and realistic data-sharing game models to better reflect the actual situation of supply chain enterprises. The data-sharing game can be explored from different perspectives, including policy level and technology levels, to comprehensively increase our understanding of the impact and mechanism of data sharing.

## Data availability statement

Data sharing does not apply to this article.

## CRediT authorship contribution statement

**Zifu Fan:** Writing – review & editing. **Zhiqiang Zhou:** Writing – original draft. **Wei Zhang:** Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.


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