Supply Chain Information Sharing Format Preferences Considering Different Power Structures

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Abstract: Through establishing a two-tier supply chain evolutionary game model with manufacturers leading and retailers as subordinates, this study explores the main factors that motivate enterprises to participate in information sharing and make strategic choices under asymmetric market power structures. It also uses simulation methods to explore the evolutionary paths and trends of these actions. The findings indicate that under conditions of unequal market positions, the intrinsic determination and willingness of the leading companies to share information become the direct driving force for the entire supply chain to engage in information sharing. These dominant businesses exploit their core market position advantages by establishing a diversified collaborative mechanism that includes both incentives and punishments, thus guiding and regulating the information sharing behavior of the subordinate companies.

Keywords: Information sharing; Asymmetric market power structures; Blockchain; Supply chain; Evolutionary game

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1. Introduction

In recent years, the frequent occurrence of natural disasters, the outbreak of COVID-19, and the increasing complexity of the business environment have made global supply chains increasingly fragile, with disruptions occurring frequently. To build a sustainable supply chain and enhance supply chain performance, information sharing and collaboration are among the key measures. Currently, many supply chains often exhibit a phenomenon of unequal market positions, particularly in sectors dominated by a few large enterprises. For instance, Toyota, as a central figure, has established close collaborative relationships with its suppliers to ensure the timely and accurate delivery of materials. This approach facilitates minimal inventory and has led to the development of the efficient Just-In-Time (JIT) production management method[1]. This imbalance in market position is typically reflected in company size, negotiation power, market control, and brand influence, resulting in larger or more influential

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companies often having greater authority and dominance over operational decisions, pricing, and contract terms. Such disparities further impact supply chain information sharing, evidenced by asymmetric information flow, exclusive control and use of data, vulnerability in trust relationships, and uneven risk distribution. To mitigate these negative effects, enterprises at various nodes need to implement effective measures to enhance information transparency and establish a more balanced data exchanging mechanism.

Blockchain, as a disruptive technology, has been widely accepted. Although it is currently still in an embryonic stage[2], its characteristics such as decentralization, trustlessness, traceability, and immutability are considered powerful tools for addressing issues of information asymmetry[3]. Utilizing blockchain technology to break the "information islands" between upstream and downstream businesses can effectively promote the collaborative development of supply chains[4]. For instance, Walmart launched the DL Freight network, which collects freight information in real-time and synchronizes it to a blockchain technology platform, making it visible to all transaction participants[5]. Maersk and IBM have collaborated to use blockchain technology to enhance data interoperability and visibility between shipping partners and foreign governments, providing all parties with a trustworthy, decentralized record of shipping data[6]. BMW Group is implementing the PartChain project aimed at using blockchain technology to achieve seamless traceability of components in the supply chain[7]. LVMH, in collaboration with luxury brands such as Prada and Cartier, has developed the Aura consortium blockchain , providing a unique platform for luxury brands to convey authentic, responsible, and sustainable information in a secure digital format[8]. Blockchain technology offers a secure, efficient, and transparent method for managing and optimizing supply chains, presenting significant potential to reduce costs, enhance operational efficiency, and strengthen mutual trust.

However, although blockchain technology ensures the authenticity of information during its transmission, it cannot rule out the possibility of the information being tampered with before it is added to the blockchain[9]. Studies have found that information sharing is not entirely complete in the equilibrium state of supply chain systems, and there is still a motive for misreporting information[10]. When analyzing the profits of the supply chain, it is found that retailers sharing true information would lead to a decrease in their own profits and an increase in their partners' profits[11]. However, if both parties can reach some sort of benefit agreement before sharing , the obstacles and the motivation for distorting information will disappear[12]. Therefore, as information or data represents a company's trade secrets and intangible assets, transparency and sharing are extremely challenging for any company. Information sharing on the supply chain not only requires technological support like blockchain but is also influenced and driven by many factors, making the willingness, strategy, and behavior of various companies a complex and dynamic game[13]. Researchers have analyzed the game process of information sharing based on the degree of trust between nodes, showing that trust mechanisms influence the willingness and environment for sharing information. They have analyzed the optimal strategies for enterprises under two scenarios: with and without the use of blockchain technology[14]. Based on the driving role of blockchain technology in supply chain, the study explores the evolutionary path of supply chain data sharing behaviors.

Relevant research typically views each node on the blockchain as a homogenous point with equal power status. By creating a technical architecture that aligns with the organizational structure of the supply chain, pathways and measures to promote collaborative information management in the supply chain are proposed. However, in practical operations, there often exists a disparity in market structure between companies, which is also reflected in the uneven initiative and enthusiasm in participating in supply chain information sharing. Although the "decentralized" nature of blockchain technically diminishes the absolute control of dominant companies over information management, the impact of unequal market positions on the participation behavior and intrinsic motivations of various companies cannot be overlooked.

Therefore, this paper constructs a research model of supply chains with unequal power structures based on the opportunities and challenges brought by blockchain technology in the application of supply chain information sharing. Utilizing evolutionary game theory, combined with multiple factors that influence the participation of micro-entities in sharing, to explore the evolutionary process of sharing behaviors between enterprises. This analysis of behavioral decisions and format preferences aims to promote stable and positive information sharing among supply chain enterprises.

2. Literature Review

(1) Information asymmetry

The causes of information asymmetry in supply chains primarily stem from two aspects[15]. Firstly, asymmetry in the transmission structure. In the supply chain, cooperation between enterprises typically involves a principal-agent relationship, where the enterprise transmitting data acts as the principal, and the enterprise receiving the data is the agent. When trust is lacking between the two parties and each entity, acting as an independent body, seeks to maximize its own interests, this can easily lead to two types of problems: adverse selection, which occurs due to pre-contractual information asymmetry, and moral hazard, which arises from post-contractual information asymmetry[16]. Secondly, obstructed in the transmission pathways. The transfer of resources in the supply chain relies mainly on the data flow for communication, if issues such as delays, errors, or losses in data transmission occur, a "bullwhip effect" can easily manifest within the supply chain[17].

Existing research has analyzed the phenomenon of information asymmetry in supply chains, including various types of data such as demand, cost, and quality[18]. Some studies focus on how data transmission under competitive market conditions influences the operational decisions of all participants[19]. Other research examines the impact of leakage risks during corporate data exchange on the competitive and cooperative relationships within the supply chain[20]. Scholars have further explored issues of information asymmetry in price-competitive environments, such as how the confidentiality of private demand information held by retailers affects incentives for data sharing when multiple retailers are in price competition[21]. By establishing a supply chain model consisting of two retailers, these studies analyze different operational strategies resulting from unidirectional versus bidirectional, and positive versus negative data exchange under various competitive scenarios[22]. Much of this research focuses on the issues of sharing private information. However, as more enterprises invest in technology and can access more information across levels[23], some studies have analyzed the sharing format preferences when both retailers and manufacturers possess the same type of information[14], [15].

Relevant research conducts an in-depth analysis of the causes of information asymmetry in supply chains and explores in detail the preferences for data sharing models and operational strategies in various market competition environments, considering different types of data, transmission directions, and cross-level information possession. These studies focus solely from an information management perspective and lack an examination of the impact from the structural characteristics of the supply chain itself.

(2) Market position and power structure

In reality, different power structures exist among supply chain enterprises, reflecting that supply chain management is dominated by various members. This can affect the operational modes and decision-making within the supply chain[24]. Research has analyzed the impact of power structures on optimal decision-making and the resultant performance in supply chains[25], and has developed models for choosing logistics modes when manufacturers and retailers respectively lead[26]. Scholars have explored how market position and product differentiation influence supply chain pricing decisions[27], and how varying power structures and uncertain demand affect the performance of supply chain members[28]. Additionally, studies have considered the differentiated pricing strategies that arise under three scenarios of power distribution: when distributors and Third-Party Logistics Service Providers (TPLSPs) individually possess channel power or when power is equally distributed among them[29].

In an environment of unequal power competition, powerful entities might strategically withhold information to maintain their competitive advantage or manipulate market conditions. Conversely, smaller or less powerful entities might withhold information as a defensive strategy to prevent exploitation by more powerful members, leading to strategic avoidance of information exchange across businesses. Additionally, imbalances in power further exacerbate mistrust among supply chain members. Nodes with less power might suspect that those in power could misuse data, thereby harming weaker parties and reducing their willingness to share crucial data. Therefore, we construct a two-tier supply chain model to consider the impact of different power structures on supply chain information management. By employing blockchain technology to ensure data transparency and traceability that can prevent unfair manipulation or retention of information, improving information flow, and enhancing the overall performance and sustainability of the supply chain.

(3) Blockchain Technology-driven

Current research primarily examines blockchain from the perspective of information flow, exploring how it affects supply chains, influences the decision-making of various stakeholders, and enables effective empowerment of supply chains. In addressing the issue of information asymmetry, blockchain's accuracy and tamper-proof characteristics help mitigate the delay in multi-tier inventory information and the occurrence of the bullwhip effect[30]. Empirical research has been conducted to explore how information governance and decentralized technologies can support and optimize the self-organization of supply chains[31]. On the issue of data exchanging and transmitting, information islands often occur due to issues of ownership and cost. Blockchain technology enables the transparent sharing of information on product quality, demand, and sustainability across the entire process[32], providing a convenient way for transaction participants to query and verify the data[33], thus becoming a key technology for effectively solving the problem of information islands[34]. In addressing the issue of enhancing information transmission efficiency, current research focuses on challenges like distributed data storage and poor interactivity. To boost blockchain consensus and the timeliness of transactions, there are designs for cross-chain information collaboration and consortium blockchain mechanisms that facilitate transactions across multiple organizations[35].At the same time, in the development of blockchain information management platforms, the focus is on establishing anti-counterfeiting and product traceability platforms to ensure genuine information sharing[36]. These platforms not only increase functionality but also enable accurate assessments of customers based on different risk types[37]. Moreover, research is being conducted on building decentralized and centralized decision-making models to compare different channel structures and to analyze the impact of blockchain anti-counterfeiting information management platforms on manufacturers' optimal decisions, consumer surplus, and social welfare[38]. Additionally, there is research exploring the willingness to share information among multiple stakeholders from a blockchain perspective. This involves developing game theory models for different structures to study the intrinsic drivers of blockchain in signal transmission within supply chains. When blockchain is not utilized, suppliers convey quality information through price signals; however, when blockchain is adopted, its high transparency ensures that data can be shared across all nodes.

Blockchain technology indeed acts as a double-edged sword in the realm of supply chain information sharing. It offers significant benefits in enhancing supply chain transparency, increasing security, and facilitating information sharing. However, it also introduces several challenges and limitations, such as the complexity of the technology, high implementation costs, risks of information leakage, and issues related to standardization and compliance. Therefore, the use of blockchain in supply chain management holds the potential to revolutionize industry practices. Businesses are prompted to engage in a dynamic decision-making process to address the challenges associated with technology and operations.

3. The Technical Pathway of Blockchain Addressing Unequal Market Positions

Blockchain technology has created a fairer and more transparent environment for information sharing in supply chains with unequal market positions. For businesses of different market positions in the supply chain, it can significantly help narrow the information gap between large and small enterprises.

(1) Fair Data Access: Blockchain provides a decentralized platform, allowing all supply chain participants, regardless of their market size, to equally access shared data, helping larger and smaller enterprises obtain the same critical information.

(2) Transparency and Traceability: Through blockchain technology, every link in the supply chain is transparently recorded, including product origin, production processes, and distribution paths, improving market information asymmetry to facilitate the establishment of effective trust relationships among all parties.

(3) Accuracy and Security: The immutability of blockchain ensures the accuracy and security of data, providing all supply chain participants with a reliable source of information.

(4) Use of Smart Contracts: Blockchain allows for the implementation of smart contracts, which can automatically execute and verify transactions in the supply chain, ensuring fair execution of contract terms regardless of the participants' market positions.

(5) Lowering Entry Barriers: Due to the typically low-cost and easy-access nature of blockchain platforms, smaller enterprises with lower market positions can more easily participate in global supply chain networks, enhancing their competitiveness.

(6) Facilitating Risk Sharing: In traditional supply chains, information is often isolated, resulting in risks primarily borne by individual businesses in the chain. Blockchain technology enables real-time data updates and visibility, allowing businesses to adjust strategies based on the latest information to mitigate potential supply chain risks and help different businesses with various market positions spread their risks.

(7) Promoting Compliance and Accountability: Blockchain can be used to record compliance data and execution processes, helping clarify accountability in the supply chain while ensuring compliance with relevant laws and regulations.

From the perspective of the supply chain system, blockchain addresses the main pain points in the circulation of goods, commercial transactions, information flow, and fund flow, enabling the efficient operation and secure application of the supply chain system. From a technical standpoint, blockchain provides a pathway for equal information sharing among supply chain enterprises with unequal market positions through five layers: the data layer, network layer, consensus layer, contract layer, and application layer.

4. Game Model of Information Sharing with Unequal Power Structures

We establish a supply chain game model where the manufacturer is in a dominant position and the retailer is in a subordinate position. In the actual process of supply chain information sharing, both the manufacturer and the retailer are boundedly rational and are influenced by internal and external factors such as capabilities, level, and risk. Therefore, neither party can find the optimal strategy initially; they need to learn and adjust through repeated games, continuously changing their strategies to achieve a stable equilibrium. To better describe the game problem between the two parties, we propose the following assumptions.

Assumption 1: In the supply chain, the manufacturer and the retailer are in a long-term cooperative relationship. When data exchanging is not implemented, each node is in a state of information asymmetry, the manufacturer chooses the sharing strategy with a certain probability x and the non-sharing strategy with another probability $1-x$; the retailer also chooses the sharing strategy with a certain probability y and the non-sharing strategy with another probability $1-y$, ensuring the total probabilities sum to 1. When both parties opt not to transmit information, the cooperative relationship still continues. Conversely, when both parties choose to exchange, the supply chain experiences a synergistic effect that enhances overall profit, creating '1+1>2' synergistic impact, represented by the synergy profit parameter g, where g>1.

Assumption 2: When only one party in the game chooses to share and the other does not, according to the 'principal-agent' theory, the party that opts to convey will lose its information advantage and may even suffer losses, while the party that chooses to receive will gain speculative profits due to the additional information advantage[53]. However, due to the unequal market power between the two parties, the dominant manufacturer, in pursuit of maximizing its own interests, can use a punitive mechanism to offset the losses incurred from its sharing when the subordinate retailer does not reciprocate. Conversely, the retailer does not possess equivalent punitive rights.

Assumption 3: Information as an intangible asset can be divided into public and private two types. Public information is fundamental to the existence of the supply chain market and acts as the driving force for transactions in the upstream and downstream. On the other hand, private information constitutes the specific resources and competitive advantages owned by each company[54]. When a party shares more private information to enhance overall synergistic efficiency, which faces greater risks of information leakage and cooperative spillovers. Hence, the risk associated with information sharing is linked both to the volume and proportion of exchanged private data Therefore, the $\mu\beta_i I$ represents the risk costs incurred from information transmission, and the risk parameter typically fall within a certain range 0<μ<0.5, indicating that companies tend to opt out of sharing when the level of associated risks becomes too high.

Assumption 4: In the process of information-sharing games, the amount of data that different companies can share varies. Additionally, due to various internal factors such as each company's operating condition, employee skill levels, management capabilities, and organizational structure, their abilities to collect, organize, and apply information also differ. As a result, the value extracted from the data and the rates of return are inconsistent. The parameter k_i represents the ability to absorb and utilize information. The value derived by a company from information sharing is calculated as the product of its ability parameter of information absorption and the amount of information shared.

Table 1: Summary of key notations

Symbol	Definitions
π_i^N	The normal profits when information is not shared
I	The amount of information
k_i	The ability to absorb and utilize information
α_i	The incentive parameter
g	The synergy parameter
c_i^B	The required input cost
μ	The risk-bearing parameter
β_i	The proportion of private information in the total
F	The punishment imposed by the dominant company for not sharing information
L_i	The losses incurred due to the other party not sharing information

The game payoff matrix for the manufacturer and the retailer is as shown in the table below:

Table 2: the game payoff matrix

The strategy combination		retailer	
		The probability of choosing the sharing strategy is y	The probability of choosing the non-sharing strategy is 1-y
manufacturer	The probability of choosing the sharing strategy is x	$(\pi_s^N + gk_sI + \alpha_sI - c_s^B - \mu\beta_sI,$ $\pi_r^N + gk_rI + \alpha_rI - c_r^B - \mu\beta_rI)$	$(\pi_s^N - c_s^B - \mu\beta_sI - L_s + F,$ $\pi_r^N + k_rI - F)$
	The probability of choosing the non-sharing strategy is 1-x	$(\pi_s^N + k_sI,$ $\pi_r^N - c_r^B - \mu\beta_rI - L_r)$	$(\pi_s^N - L_s,\ \pi_r^N - L_r)$

5. Analysis of Evolutionarily Stable Strategy

The strategic choices of both parties in the game jointly determine their respective final payoffs. Therefore, an analysis of the dynamic evolution of game strategies is conducted based on the payoff matrix for manufacturer and retailer.

(1) Analysis of evolutionarily stable strategy for manufacturer

The expected payoff for manufacturer choosing the sharing strategy is:

$$U_{S1} = y(\pi_s^N + gk_sI + \alpha I - c_s^B - \mu\beta_sI) + (1-y)(\pi_s^N - c_s^B - \mu\beta_sI - L_s + F) \quad (1)$$

Correspondingly, the expected payoff for manufacturer choosing the non-sharing strategy is:

$$U_{S2} = y(\pi_s^N + k_sI) + (1-y)(\pi_s^N - L_s) \quad (2)$$

The average expected payoff for manufacturer is:

$$\overline{U_S} = xU_{S1} + (1-x)U_{S2} \quad (3)$$

The replicator dynamics equation for manufacturer choosing the sharing strategy is:

$$F_x = \frac{d_x}{d_t} = x(U_{S1} - \overline{U_S}) = x(1-x)(F(1-y) - c_s^B + k_sIy(g-1) + \alpha Iy - \mu\beta_sI) \quad (4)$$

By setting the formula F_x=0, three possible evolutionary game equilibrium points can be identified:

$$x_1^* = 0$$

$$x_2^* = 1$$

$$y^* = \frac{F - c_s^B - \mu\beta_sI}{F - k_sI(g-1) - \alpha I}$$

According to the stability theorem of differential equations, it is known that when the first-order derivative formula F_x=0 and the second-order derivative formula $F_x^{'}$<0 are satisfied, this represents a stable strategy in evolutionary game theory. Therefore, further solving the second-order derivative and analyzing the stable strategy for manufacturer follows:

(1)When $y = y^* = \frac{F-c_s^B-\mu\beta_sI}{F-k_sI(g-1)-\alpha I}$, $F_x = \frac{d_x}{d_t} = 0$, and $F_x^{'}$=0, the above three possible evolutionary game equilibrium points are all stable strategies. The outcome for manufacturer choosing between the strategies of sharing or non-sharing is the same.

(2)When $y \neq y^* = \frac{F-c_s^B-\mu\beta_sI}{F-k_sI(g-1)-\alpha I}$ and $F_x = \frac{d_x}{d_t} = 0$, then x_1^*=0 and x_2^*=1 are both possible stable strategies for the manufacturer, which we will explain by categorizing:

a)When $y^* = \frac{F-c_s^B-\mu\beta_sI}{F-k_sI(g-1)-\alpha I} > 1$ and $0 \le y \le 1$, then at the evolutionary game equilibrium point x_1^*=0 satisfying the requirement $F_{x_1^*}^{'} < 0$, it indicates that the manufacturer will choose non-sharing as a stable strategy.

b)When $y^* = \frac{F-c_s^B-\mu\beta_sI}{F-k_sI(g-1)-\alpha I} \le 1$ and $0 \le y < \frac{F-c_s^B-\mu\beta_sI}{F-k_sI(g-1)-\alpha I}$, it still satisfies the condition $F_{x_1^*}^{'} < 0$ at the evolutionary game equilibrium point x_1^*=0, it also indicates that the manufacturer will tend to choose the same non-sharing strategy.

c)Only when $y^* = \frac{F-c_s^B-\mu\beta_sI}{F-k_sI(g-1)-\alpha I} \le 1$ and $\frac{F-c_s^B-\mu\beta_sI}{F-k_sI(g-1)-\alpha I} < y \le 1$, then at the evolutionary game equilibrium point x_2^*=1 satisfying the requirement $F_{x_1^*}^{'} < 0$, indicating that the manufacturer willing to adopt sharing as a stable strategy.

(2) Analysis of evolutionarily stable strategy for retailer

The expected payoff for retailer choosing the sharing strategy is:

$$U_{r1} = x(\pi_r^N + gk_rI + \alpha I - c_r^B - \mu\beta_rI) + (1-x)(\pi_r^N - c_r^B - \mu\beta_rI - L_r) \tag{5}$$

Correspondingly, the expected payoff for retailer choosing the non-sharing strategy is:

$$U_{r2} = x(\pi_r^N + k_rI - F) + (1-x)(\pi_r^N - L_r) \tag{6}$$

The average expected payoff for retailer is:

$$\overline{U_r} = yU_{r1} + (1-y)U_{r2} \tag{7}$$

The replicator dynamics equation for retailer choosing the sharing strategy is:

$$F_y = \frac{d_y}{d_t} = y(U_{r1} - \overline{U_r}) = y(1-y)(x(F + \alpha I + (g-1)k_rI) - c_r^B - \mu\beta_rI) \tag{8}$$

By setting the formula F_y=0, three possible evolutionary game equilibrium points can be identified:

$$y_1^* = 0$$

$$y_2^* = 1$$

$$x^* = \frac{c_r^B + \mu\beta_rI}{F + \alpha I + (g-1)k_rI}$$

Similarly, according to the stability principle of differential equations, by further calculating the second derivative, the stable strategy for the retailer can be determined as follows:

(1)When $x = x^* = \frac{c_r^B+\mu\beta_rI}{F+\alpha I+(g-1)k_rI}$, $F_y = \frac{d_y}{d_t} = 0$, and F_y' =0, the above three possible evolutionary game equilibrium points are all stable strategies. The outcome for retailer choosing between the strategies of sharing or non-sharing also is the same.

(2)When $x \neq x^* = \frac{c_r^B+\mu\beta_rI}{F+\alpha I+(g-1)k_rI}$ and $F_y = \frac{d_y}{d_t} = 0$, then y_1^*=0 and y_2^*=1 are both possible stable strategies for the retailer, which we will explain separately as before:

a)When $x^* = \frac{c_r^B+\mu\beta_rI}{F+\alpha I+(g-1)k_rI} > 1$ and $0 \le x \le 1$, then at the evolutionary game equilibrium point y_1^* =0 satisfying the requirement $F_{y_1^*}'$ <0, it indicates that the retailer will similarly choose non-sharing as a stable strategy.

b)When $x^* = \frac{c_r^B+\mu\beta_rI}{F+\alpha I+(g-1)k_rI} \le 1$ and $0 \le x < \frac{c_r^B+\mu\beta_rI}{F+\alpha I+(g-1)k_rI}$, it still satisfies the condition $F_{y_1^*}'$ <0 at the evolutionary game equilibrium point y_1^*=0, it also indicates that the retailer will choose the same non-sharing strategy.

c)Only when $x^* = \frac{c_r^B+\mu\beta_rI}{F+\alpha I+(g-1)k_rI} \le 1$ and $\frac{c_r^B+\mu\beta_rI}{F+\alpha I+(g-1)k_rI} < x \le 1$, then at the evolutionary game equilibrium point y_2^*=1 satisfying the requirement $F_{y_2^*}'$<0, indicating that the retailer willing to adopt sharing as a stable strategy.

6. Stability Analysis of the Game Equilibrium Point

Using the Jacobian matrix stability analysis method, analyze the local stability of the evolutionary equilibrium point of the information-sharing behavior between the two parties. The Jacobian matrix derived from this game model analysis is as follows:

$$J = \begin{bmatrix} (1-2x)(F(1-y) - c_s^B + k_sIy(g-1) + \alpha Iy - \mu\beta I) & x(1-x)(k_sI(g-1) + \alpha I - F) \\ y(1-y)(F + \alpha I + (g-1)k_rI) & (1-2y)(x(F + \alpha I + (g-1)k_rI) - c_r^B - \mu\beta I) \end{bmatrix}$$

Due to the information sharing behavior between the parties, a relatively effective Nash equilibrium is achieved through dynamic adjustments in decision-making and continuous accumulation of experience. Consequently, by combining the potential evolutionary game equilibrium points of both parties, we analyze the five local evolutionary game equilibrium points of the information-sharing game and separately calculate the determinants and traces of the corresponding Jacobian matrices.

Table 3: The determinants and traces of the Jacobian matrices at different equilibrium points

The equilibrium points	$detJ$	TrJ
(0,0)	$C_rC_s - C_rF + \mu\beta I(\mu\beta I + C_r + C_s - F)$	$F - C_s - C_r - 2\mu\beta I$
(0,1)	$-(\mu\beta I + C_r)(C_s - \alpha I + k_sI(1-g) + \mu\beta I)$	$C_r - C_s + \alpha I + (1-g)k_sI$
(1,0)	$-(\mu\beta I + C_s - F)(\mu\beta I + C_r - F - \alpha I + (1-g)k_rI)$	$C_s - C_r + \alpha I - (1-g)k_rI$
(1,1)	$(C_s - \alpha I + (1-g)k_sI + \mu\beta I)(C_r - \alpha I - F + (1-g)k_rI + \mu\beta I)$	$C_s + C_r - F + 2\mu\beta I - 2\alpha I + (1-g)k_rI + (1-g)k_sI$
(x^*, y^*)	$(C_r + \mu\beta I)(C_r - F + \mu\beta I)(C_r - \alpha I + \mu\beta I + (1-g)k_sI)(C_r - \alpha I + \mu\beta I + (1-g)k_rI)/((F + \alpha I - (1-g)k_rI)(F - \alpha I + (1-g)k_sI))$	$((C_r - C_s)(2C_r - F - \alpha I. + k_rI - gk_rI + 2\mu\beta I))/(F + \alpha I - k_rI + gk_rI)$

If an equilibrium point satisfies detJ > 0 and trJ < 0, then it is one of the system's Evolutionarily Stable Strategies (ESS). The numerical analysis results for the stability of the equilibrium points are as follows in the table below:

Table 4: Numerical analysis of the stability of different equilibrium points

The equilibrium points	① $C_r > F$			② $C_s + \mu\beta I < \alpha I + (g-1)k_sI$， $C_r + \mu\beta I - F < \alpha I + (g-1)k_rI$，且 $C_r > F$			③ $C_s + \mu\beta I < \alpha I + (g-1)k_sI$， $C_r + k_rI + \mu\beta I - F < \alpha I + gk_rI$，且 $C_r < F$		
	$detJ$	TrJ	Stability	$detJ$	TrJ	Stability	$detJ$	TrJ	Stability
O(0,0)	+	-	ESS	+	-	ESS	uncertainty	uncertainty	saddle point
E_1(0,1)	uncertainty	uncertainty	saddle point	uncertainty	uncertainty	saddle point	uncertainty	uncertainty	saddle point
E_2(1,0)	uncertainty	uncertainty	saddle point	uncertainty	uncertainty	saddle point	uncertainty	uncertainty	saddle point
E_3(1,1)	uncertainty	uncertainty	saddle point	+	-	ESS	+	-	ESS
$E_4(x^*, y^*)$	uncertainty	uncertainty	saddle point	uncertainty	uncertainty	saddle point	uncertainty	uncertainty	saddle point

From the calculations in the above table, in the information-sharing game where the manufacturer leads and the retailer follows, only O(0,0) and E_3(1,1)among the five local equilibrium points are stable, corresponding to both parties adopting non-sharing and sharing strategies at the same time. The other points are either unstable or saddle points. Detailed analysis follows:

When $C_r > \mathrm{F}$, then O(0,0) is the only evolutionarily stable equilibrium point. At this time, due to the manufacturer's dominant position, there are certain restrictions on the retailer's participation in information sharing, namely a mechanism that enforces penalties for non-participation. From the retailer's perspective, if the cost of exchanging data exceeds the penalties for non-exchanging, it indicates that the manufacturer's control is somewhat limited. In the face of uncertainty about the manufacturer's decisions, the retailer aiming to maximize its own benefits, will opt not to share information. From the manufacturer's perspective, since the retailer is adamant about non-sharing choice, and in the absence of a clear incentive mechanism for sharing between both parties, they will also not adopt a strategy of sharing, leading to a vicious cycle.

When $C_s + \mu\beta I < \alpha I + (g-1)k_s I$, $C_r + \mu\beta I - F < \alpha I + (g-1)k_r I$, and $C_r > F$, there are two evolutionarily stable equilibrium points: O(0,0) and E(1,1). For manufacturer, the sum of costs and risks associated with sharing information is less than the combined potential rewards from incentives and collaboration, providing them with motivation and willingness to share information. For retailers, even though the costs and risks of sharing information, minus the penalties for non-sharing, are less than the sum of achievable incentive earnings and collaborative benefits, the cost of participating in information sharing is significant. Moreover, the constraints placed on the choice to not share by manufacturer are relatively limited, leading to a weaker willingness to share information and less pronounced benefits from incentives.When manufacturer who hold a dominant position, do not have a strong willingness to share information, it further demotivates retailers from adopting the same strategy. Therefore, the equilibrium points (0,0) and (1,1) are both evolutionarily stable strategies (ESS).

When $C_s + \mu\beta I < \alpha I + (g-1)k_s I$, $C_r + \mu\beta I - F < \alpha I + (g-1)k_r I$, and $C_r < F$, $E_3(1,1)$ is the only evolutionarily stable equilibrium. This implies that for manufacturer, the sum of the costs and risks associated with sharing information is less than the total potential benefits from incentives and collaboration, motivating it to actively choose the sharing strategy. For retailer, when the penalty for not participating in sharing is substantial, or the cost of participating is minimal, the pursuit of profit maximization similarly empowers it to boldly adopt the sharing strategy, even in the face of uncertainty about whether the manufacturer will share or not. Thus, for both manufacturer and retailer, actively choosing to share information aligns maximally with their interests. Therefore, the ultimate equilibrium point $E_3(1,1)$ is the sole ESS.

7. Numerical Experiment and Simulation

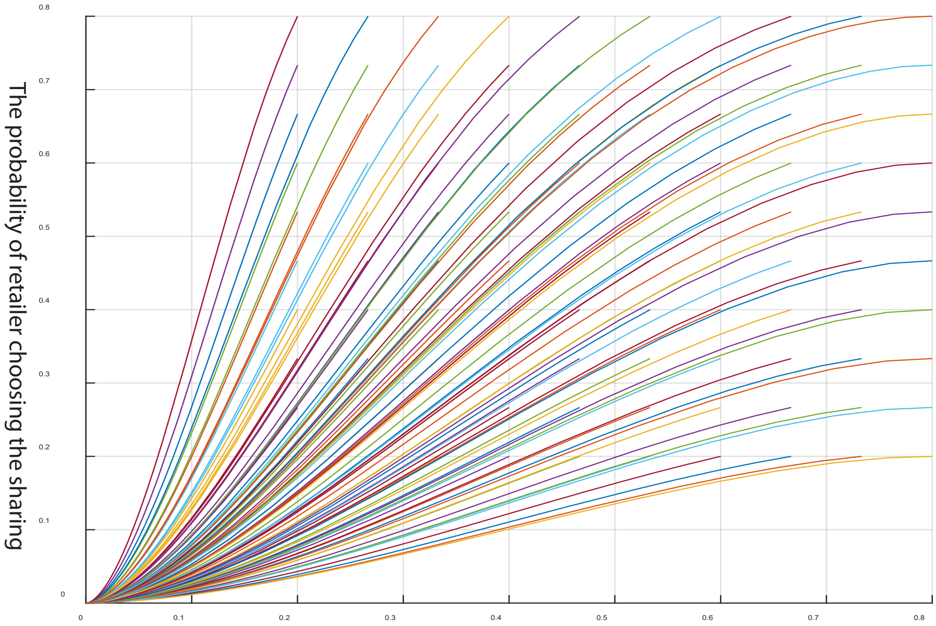
The focus of simulations is to analyze the impact of key elements on game-theoretic equilibrium and explore how to achieve the ideal results. The expected equilibrium state is when both parties in the supply chain are actively sharing information. To more directly observe the effects of variables changes on the decisions of the participants, we use MATLAB software to conduct numerical experiments and simulation, investigating the ideal equilibrium evolutionary paths for both parties to actively share information.

The setting of model variables must conform to economic assumptions and empirical judgments. Based on the research experience of predecessors and objective facts, the initial values of the model variables are assumed as shown in the following table.

Table 5: Initial Variable Values

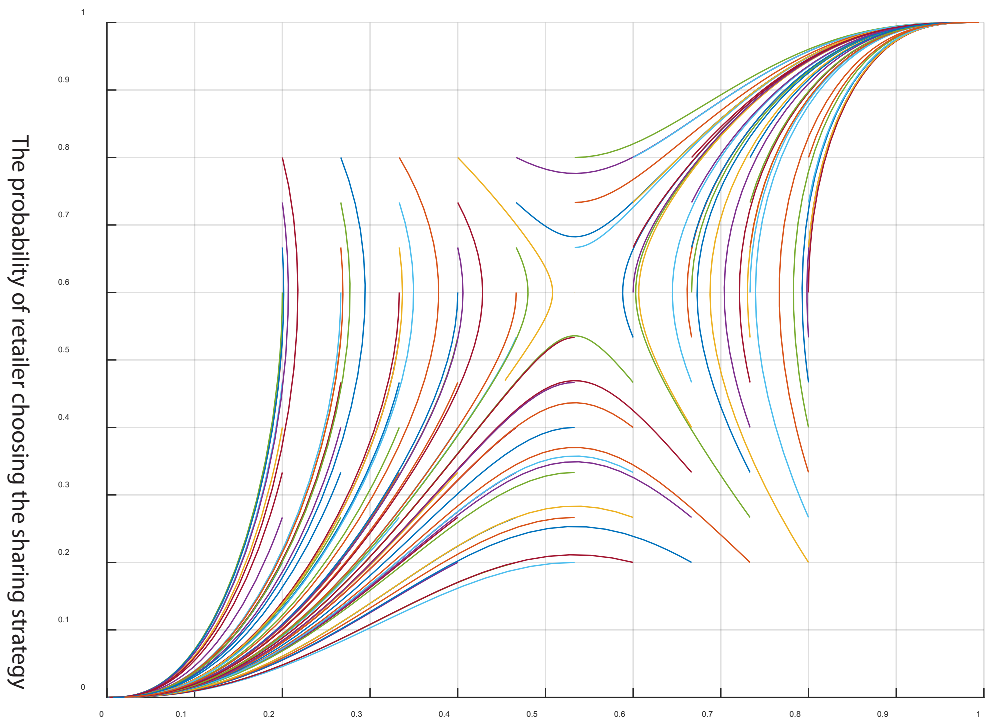
C_s	2	C_r	2
α	0.5	g	2
K_s	0.5	K_r	0.5
μ	0.4	β	0.5
F	1	I	2

When $C_s > F$, among the five equilibrium points, only O(0,0) is stable. Therefore, we set the cost variables C_s and C_r for technological investment in information sharing for both parties at 2, and the penalty imposed by manufacturer on retailer who opt not to share information at 1, thus ensuring $C_s > F$. The simulation results show that, regardless of the initial intentions of the game participants, the outcome invariably converges to O(0,0). This indicates that both parties will choose the strategy of non-sharing , consistent with the evolutionary game model analysis presented earlier. The simulation results are illustrated in the diagram5.



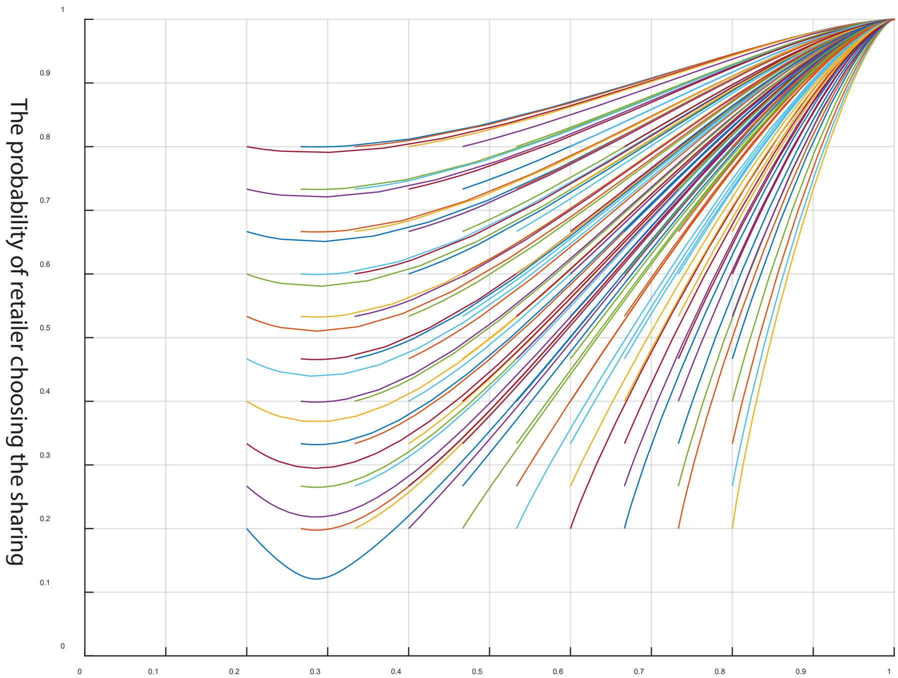
The probability of manufacturer choosing the sharing strategy
Diagram1 Initial results of the dynamic evolution simulation

When the values of the technological investment cost variables for both manufacturer and retailer in the model are reduced from 2 to 1.2, while keeping the values of other variables constant, both parties begin to experiment with the choice to share information. However, their willingness is not very strong, leading to a dual possibility of either choosing to share or not. The evolutionary equilibrium outcomes tend toward either O(0,0) or (1,1). The simulation of evolutionary path is shown in diagram6.



The probability of manufacturer choosing the sharing strategy
Figure 2. Adjustment Diagram of Dynamic Evolution for tech- nological investment cost Values

As the technological investment cost variables C_s and C_r in the model are further reduced from 1.2 to 0.8, enabling the cost for retailers to participate in sharing to be lower than the penalties for not participating, i.e., C_s > F; and simultaneously, the incentive parameters α_i for both parties to choose a sharing strategy and their ability parameters k_i to absorb and utilize information are increased from 0.5 to 0.8, the participants are significantly influenced by the synergistic benefits arising from information sharing. The simulation results show that both sides actively opt for the sharing strategy, thus fostering a scenario of supply chain collaboration.



The probability of manufacturer choosing the sharing strategy
Figure 3 . Adjustment Diagram of Dynamic Evolution for incen- tive parameter and the ability to absorb and utilize information Values

8. Conclusions

To explore the enthusiasm and evolutionary process of information sharing among nodes in an unequally positioned supply chain under a blockchain architecture, this paper constructs a two-sided information-sharing game model with manufacturer as leader and retailer as follower. It analyzes the evolutionary stability of strategy choices by all parties and validates the analysis through numerical simulations. The research findings indicate that a reasonable incentive mechanism for information sharing can drive the supply chain to form an ideal situation where multiple entities actively participate in cooperation. Additionally, punitive measures serve as an important means to prevent subordinate enterprise from exploiting data from leading enterprise without actively sharing its own data. Opportunistic behaviors may exist in the utilization of shared data, and reasonable punitive measures can effectively prevent such occurrences. Lastly, reducing technical investment and controlling the risk of information leakage, as well as improving enterprise informatization levels and data utilization capabilities, are important measures to promote information sharing in the supply chain.

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