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Exploring the Optimization Path of Blockchain Technology Implementation Strategy under Shared Supply Chain

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Abstract With the rapid development of digital economy, blockchain technology, with its characteristics of decentralization, information tampering, distributed bookkeeping and storage, provides new ideas to solve the trust dilemma in supply chain collaborative sharing. Based on the characteristics of blockchain technology and evolutionary game theory, this study constructs a strategy optimization model for the implementation of blockchain technology under the shared supply chain, analyzes the sensitivity of the technical impact parameters through numerical simulation, and proposes optimization paths at the government and enterprise levels. The study adopts the replication dynamic equation and the evolutionary stability strategy as the theoretical basis, and establishes a supply chain sharing model to analyze the impact mechanism of collaborative information sharing on production cost and profit. The results show that: with the increase of the ability coefficient of supplier's blockchain technology effort level, the optimal incentive coefficient and revenue of the manufacturer to the supplier, and the effort level of supplier information sharing are on an upward trend; with the increase of the supplier's risk aversion coefficient, the optimal incentive coefficient of the manufacturer to the supplier decreases from 0.765 to 0.625, and the optimal effort level of the supplier's information sharing is on a downward trend; and with the subsidy constrained case, the manufacturer benefits decrease as supplier retention utility rises. The optimization path validation analysis shows that in the enterprise satisfaction survey of five dimensions (reliability, responsiveness, agility, security, and convenience), 51-60 enterprises are satisfied and 14-31 enterprises are more satisfied, which confirms the practical application value of the optimization path. The study provides theoretical basis and practical guidance for the optimization of implementation strategy of blockchain technology in shared supply chain.

Index Terms blockchain technology, shared supply chain, evolutionary game, strategy optimization, information collaboration, incentive mechanism

I. Introduction

The innovative development of digital technology promotes industrial transformation and upgrading, and the scale of the digital economy is expanding, which has become a key force in reshaping the global economic structure and changing the pattern of competition, and is also an important choice for developing countries to promote development and realize “lane-changing” [1]-[3]. Especially in the new crown epidemic to the global socio-economic development caused by the huge impact of the background, the digital economy shows a strong development of resilience, from a particular perspective interpretation of the “century without great change” unique meaning [4]. Data is the micro-foundation and innovation engine of the digital economy, and the ability to establish a large-scale data market and internalize it into productivity has become an important foundation for a country or region to obtain strategic opportunities [5].

Data elements have the characteristics of virtuality, non-competitiveness, non-exclusivity, etc. Thus, supply chain network data sharing faces the problems of ill-defined data ownership among members, uneven distribution of sharing benefits, inconsistent data standards, leakage of core data, etc., which form data islands [6]-[8]. In addition, in the process of data sharing, there are opportunistic behaviors that deviate from the overall interests of the supply chain network, and the high speculative gains will make the data sharing enthusiasm and mutual trust among the supply chain network members decline rapidly, resulting in the “inverted U” curve of supply chain network data sharing, which greatly reduces the efficiency of the supply chain network collaboration [9]-[12]. In the actual transaction, due to the existence of potential opportunistic risk, the failure rate of supply chain network cooperation is as high as 50%~70% [13]. Therefore, there is an urgent need to innovate supply chain network digital governance model with the help of intelligent technology to solve the data silo problem, break through the opportunistic dilemma, and promote supply chain network digital change.

Blockchain is the most disruptive technology in the fourth industrial revolution, which has been successfully applied to supply chain finance, logistics and other fields [14]. Scholars focus on the ways in which blockchain technology empowers supply chains mainly from three aspects: information sharing, information traceability and trust establishment [15]. In terms of information sharing, the authenticity of data transmission of business processes in the supply chain is guaranteed. Blockchain timestamps the data blocks, generates heterogeneous data, and realizes the automatic conversion of property rights between different subjects through smart contracts when circulating, and hash algorithm guarantees data security [16]-[18]. At the same time, blockchain technology has “immutability”, which lays a trust cornerstone for data transmission and storage, and provides data authentication and authenticity proof between different subjects [19]. The application of blockchain technology provides a new solution to solve the dilemma of data sharing in supply chain networks, ensures that supply chain network members share data in a trustful and transparent way, and establishes a new trust model of upstream and downstream subgroups' interconnectivity [20]. Currently, several supply chain networks have applied blockchain technology for data sharing, such as Mengniu financial sharing platform, Walmart, etc., but they face problems such as insufficient willingness to share and inefficient sharing.

Blockchain, as the fifth wave of disruptive innovation following the steam engine, electricity, information and Internet technology, is profoundly changing the global industrial development pattern. This integrated innovation of distributed data storage, peer-to-peer transmission, consensus mechanism, cryptographic algorithms and other technologies provides technical support for solving supply chain pain points such as information asymmetry and lack of trust mechanism. Currently, the global supply chain is facing a series of challenges such as information silos, inefficient collaboration, high transaction costs, poor traceability, etc. The traditional centralized management mode is difficult to adapt to the complex and changing market environment. Blockchain technology, through its decentralization, non-tampering of information, automatic execution of smart contracts and other characteristics, can build a trust mechanism among supply chain subjects, reduce transaction costs, and enhance information transparency and collaboration efficiency. The integration and development of blockchain and supply chain has become a hotspot of attention in academia and industry, and related research mainly focuses on technical application scenarios, business process reshaping, and governance mechanism innovation. However, there is a relative lack of systematic research on the optimization of blockchain technology implementation strategy in shared supply chain, especially the lack of quantitative analysis framework based on evolutionary game perspective, which makes it difficult to accurately grasp the key influencing factors and optimization paths in the implementation process of blockchain technology.

Existing research at home and abroad mainly focuses on the application value and model innovation of blockchain technology, and pays insufficient attention to the strategy selection and path optimization in the implementation process. First, most of the research stays at the conceptual level and lacks the support of quantitative analysis; second, it fails to fully consider the characteristics of the evolutionary behavior of each subject of the supply chain in the process of blockchain implementation; and third, there are fewer systematic solutions on the optimization path of the implementation strategy. Based on this, this study builds a blockchain technology implementation strategy optimization model based on the evolutionary game theory to explore the influence mechanism of different parameters on the decision-making behavior and benefits of manufacturers and suppliers, so as to reveal the inherent rules and optimization path of blockchain technology implementation in the shared supply chain. The study will first analyze the core technology characteristics of blockchain and the operation mechanism of the shared supply chain, and then construct an evolutionary game model on this basis to explore the strategic evolution paths of manufacturers and suppliers in the process of blockchain technology implementation by replicating dynamic equations and analyzing stable strategies. We further analyze the sensitivity of technical influence parameters through numerical simulation, and propose the optimization path of blockchain technology implementation strategy from both government and enterprise levels, and finally verify the practical value of the optimization path through enterprise satisfaction survey. This study will provide theoretical guidance and decision-making reference for promoting the deep integration of blockchain technology and shared supply chain.

II. Exploration of Blockchain Technology from the Perspective of Shared Supply Chain

II. A. Blockchain core technology

II. A. 1) Blockchain characteristics

Blockchain technology mainly relies on decentralized deployment, peer-to-peer bookkeeping through transaction records and subsequent tracking queries, and privacy protection achieved through encryption, with the following specific features:

(1) Decentralized architecture

The decentralized architecture is different from the centralized deployment of large databases nowadays, and adopts multi-node, distributed deployment [21]. At the same time, through mathematical and cryptographic methods, a trust relationship is established between business scenarios and data that require manual operation.

(2) Data information cannot be tampered with

The composition of data information adopts the method of data block plus time stamp, and the block contains the buyer and seller of the transaction, as well as the occurrence time, amount, and address of the transaction [22]. After each block is confirmed, it will be marked by the time stamp, and the newly generated block contains the ID of the previous block and the newly generated ID of this block, forming a series of electronic transaction certificates established through the network, and each node has a copy of the data and can be exchanged with each other so as to ensure that the data cannot be tampered with.

(3) Distributed bookkeeping and storage

The bookkeeping process of blockchain is a process of distributed bookkeeping and distributed storage of data, and each participating node will save the same information. After completing the bookkeeping, the block broadcasts the data to other nodes in the network [23]. In addition, distributed deployment brings the advantage that even if some nodes in the network are abnormal, it still does not affect the bookkeeping and storage of other nodes.

II. A. 2) Blockchain types

Blockchain can be categorized into public chain, private chain, federation chain and side chain according to the form of users' access to it. Public chain can be understood as the public sharing platform of blockchain, people can read the data on the public chain at any time, confirm the transaction and get the query result at any time, and participants all over the world can join in the process of consensus building. Private chain is a distributed database on the read and write access to make restrictions. Coalition chain can be used in certain industries where multiple companies form a coalition to achieve small-scale data sharing, and each node on the coalition chain can be an entity that joins and exits the blockchain network through authentication. Sidechain, which allows any node in the blockchain network to be used as a starting point for encrypted computation, the blockchain operations follow the proof-of-work method and follow the longest mechanism of the main chain to keep the data unique.

II. A. 3) Blockchain consensus mechanisms

The core technology of Bitcoin is a decentralized, replicable, publicly transparent ledger constructed by the blockchain and shared by all network nodes. The most critical achievement of this technology is that it allows the world to be monitored by the entire population without relying on a third party to prove its trustworthiness and to confirm that these transactions of transferred funds are unique. For the entire P2P network to keep the same records, it requires that the participants in the network adhere to a uniform protocol, which we have become the consensus algorithm. The rules of consensus include the proof-of-work method and the longest chain mechanism.

II. A. 4) Smart Contracts

A smart contract is implemented through blockchain technology, but unlike other contracts it is compiled through a program to form a digital contract. The smart contract can track the usage records of the funds after they are acquired, and when it is found that the funds have not been used in accordance with the constraints in the contract, the system will activate an early warning. Investors can be the first to understand the default behavior and take measures. For borrowers who provide funds by way of inventory pledge can freeze the borrower's assets. The use of smart contracts effectively ensures the rights and obligations of both parties to the contract, and also effectively reduces the occurrence of fraud.

II. A. 5) Cross-border payments

The traditional means of cross-border payment is mainly realized through banks, domestic and foreign clearing organizations, and there is a single clearing organization globally, which lacks competitiveness, and users need to pay high transaction fees in cross-border payment, and the time of settlement is also unilaterally decided by the clearing organization, so that the user experience of the whole transaction process is poor. The transaction starts from the payer's transaction system and reaches the bank's transaction system, during which each bank has to do information interaction in its own system, which is slow and costly. Blockchain cross-border settlement platform can bypass the many systems, so that the two sides of the transaction to carry out end-to-end transactions, through the blockchain, the construction of a cross-border payment between banks, real-time clearing of currencies platform, to create a more direct, lower cost, better efficiency between the payer and payee transaction mode.

II. A. 6) The Ethernet system

Through blockchain technology, Ether aims to create a decentralized application community that incorporates key technologies from several fields such as artificial intelligence, cryptography, and communication networks. While Ether relies on blockchain technology, it needs a more robust scripting system to transform it into another blockchain platform that is community-based, transactional, and can be automated through code or programs. In a way, we can think of Ether as a derivative of blockchain and smart contracts, a platform that allows anyone to create smart contracts or decentralized applications. As a platform, Ether can utilize a variety of blockchains and protocols and each node can run distributed programs and sell them to users. With blockchain as the technological basis, blockchain compilation through the program is the basis for the formation of smart contracts, based on smart contracts can be code means to create a shared supply chain of blockchain applications, the two complement each other.

II. B.Evolutionary games

The research content of evolutionary game theory is mainly after the evolution of time, how the limited rationality of the game subject in the continuous repetition of the game process, through a certain amount of learning to change the strategy, improve their own benefits [24]. Evolutionary game theory is a combination of evolutionary ideas in biology and relevant principles in game theory, to realize the evolutionary analysis between the game subject and dynamic time, explaining the dynamic evolution process between the game subject, the trend of the game subject's strategy choices in this process, and the reasons for the change of strategy choices. Evolutionary game theory converts the essence of evolutionary theory in biology into evolutionary ideas, and combines the basic principles of game theory to realize the evolutionary analysis between time dynamics and the subject game, which provides a useful inquiry method for people to understand the dynamic evolution between the subjects of the game and the behavioral choices made by the subjects in the process, as well as the reasons why they make such choices. The evolutionary game is not about getting the optimal strategy of the game subjects, but its core is the evolution process, trend and final stable state of the strategy choices of the finite rational game subjects with the passage of time and the repetition of the game process. This subsection will provide a detailed theoretical description of the replication dynamic equations and fireworks stabilization strategies in evolutionary game theory, which will provide solid theoretical support for the following research work to be carried out.

II. B. 1) Replicating the dynamic equations

The replication dynamic equation is proposed based on the theoretical idea of mathematical frequency, which describes the dynamic differential equation of the frequency of a small group choosing a particular strategy in a large group. Replication dynamics is the basic dynamics of evolutionary game theory, focusing on the selection mechanism of the game subject and emphasizing the important role of strategy selection in the game. The replication dynamic equation can better depict the behavioral change trend of a finite number of individuals (choosing strategy - evolution - choosing a new strategy - re-evolution), and can more accurately predict the behavior of individuals, and its basic idea is that the benefit obtained by an individual after choosing a certain strategy is higher than the group's evaluation of the payment, then in the The basic idea is that if an individual's gain after choosing a strategy is higher than the group's evaluation payment, then more and more individuals in the group will choose that strategy, and vice versa. According to the basic idea of evolutionary game theory, if the gain obtained by choosing a certain strategy in the game is higher than the average gain of all the strategies, then this strategy will be adopted by all the subjects of the game, which can be expressed by the differential equation as follows:

$$\frac{dx_i}{dt} = x_i\left[f(s_i, x) - f(x, x)\right], i = 1, 2, ..., n \tag{1}$$

where i is the strategy chosen by the subject of the game, x_i is the probability that the subject of the game chooses i strategy, $f(s_i, x)$ denotes the expected payoff gained from choosing i strategy, and $f(x,x) = \sum x_i f(s_i, x)$ denotes the average of all the strategies of the subject of the game. Returns.

II. B. 2) Evolutionary stabilization strategies

The main idea of the evolutionary stable strategy is that, assuming that there exists a small group that chooses a different strategy in a large group that chooses exactly the same strategy, the small group can invade the original game group if it can obtain a higher payoff than the original game group; otherwise, it will be eliminated. If a large group can avoid the invasion of any small group, the group reaches an evolutionary stable state, and the strategy chosen by the group is an evolutionary stable strategy. By analyzing the replication dynamic equation, the evolutionary stable strategy of the game group can be found. Make the replicated dynamic equation equal to 0, find all the stable solutions of the replicated dynamic equation, and then discuss the stability of the neighborhood of these stable states, which can be called the real evolutionary stable strategy only when they reach the "equilibrium state that is robust to small perturbations". The mathematical description is:

If the policy x^* is satisfied:

When $x < x^*$, copy the dynamic equation $\frac{d}{x}dt = F(x) < 0$.

When $x > x^*$, replicate the dynamic equation $\frac{d}{x}dt = F(x) < 0$.

Then the strategy x^* is called evolutionarily stable.

II. C.Blockchain-based supply chain sharing model

II. C. 1) Supply chain network system

Figure 1 mainly shows the connection between the upstream and downstream of the supply chain between enterprises outside the supply chain, the interaction between enterprises at the same level is not highlighted. Among them, CA indicates the node authentication center, by the supply chain business main body each as the authentication center on the supply chain of the identity information of each business main body as well as the authenticity and reasonableness of the information of each link of the product or service transaction to certify, the customer's own random joining and leaving has a strong instability, so do not consider the product customers as the authentication of the main center, but the final customer can be authorized under the premise of the blockchain Data access. The business transaction information in the supply chain is not stored independently by the business subject that releases the information, but is stored in the block after the consensus authentication by the authentication center and then distributed by the authorized authentication center, and all subjects in the chain can access it under the premise of authorization, and there will be no effect of the step-by-step amplification of the demand information from the demand side to the supply side in such a collaborative sharing mode to alleviate the impact of the bullwhip effect, and the role of the consensus mechanism The role of consensus mechanism guarantees the truthfulness and reliability of the information stored in the supply chain, and the automated execution of smart contracts improves the efficiency of the overall coordinated operation of the supply chain.

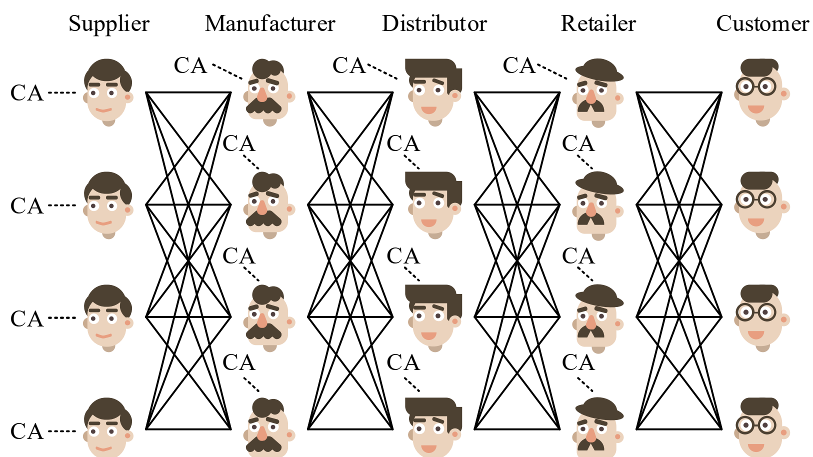


Figure 1: The supply chain network system based on blockchain

II. C. 2) Supply chain operation process

Combined with the mechanism of blockchain technology, it describes the operation process of relevant business collaboration under the supply chain information sharing based on blockchain technology, including the network-wide broadcasting of raw material or finished product procurement information, inventory information of each business entity, product sales information and material distribution information, consensus authentication by the authentication center, the automatic execution of smart contracts for procurement management and inventory of each business entity, the automatic execution of smart contracts for sales management and product logistics and distribution of authorized entities, as well as the distribution of bookkeeping and storage of business transaction information with consensus authentication. Automatic execution of smart contracts for procurement management and inventory of each business entity, sales management and product logistics and distribution of retailers, as well as distribution of bookkeeping and storage of consensus-authenticated business transaction information by authorized entities. On the whole, blockchain technology enables the optimal integration of supply chain information resources, realizes the breakthrough of intelligent supervision of supply chain business content, and brings a brand-new realization mode of supply chain information cooperation and sharing.

II. C. 3) Construction of Supply Chain Sharing Models

The decentralized and de-trusted characteristics of blockchain technology make the complex supply chain network more orderly and stable, and the node enterprises are willing to share information to improve the overall synergy of the supply chain. The information of business transactions in the supply chain, including product procurement, inventory, sales, logistics and distribution, is related to the degree of blockchain technology application. For these operational processes, the supply chain combines blockchain core technology and evolutionary game theory to construct a supply chain sharing model.

The unit production cost of raw materials set by supplier firm i is c_{si}, c_{mi} denotes the initial unit production cost set by manufacturer firm i, the wholesale price of the product set by the supplier is w_i, the selling price of manufacturer firm i is p_i, and q_i is the quantity of product ordered by manufacturer firm i, a is the market price, and b is the size of marginal cost. $\lambda_{ij}(0<\lambda_{ij}<1, i\neq j)$ is the degree of substitution between the two products, and also indicates the intensity of competition between the two firms $\lambda_{ij}=\lambda_{ji}, a>0, b>0, 0<\lambda<1$. The production cost is related to the production process, technology level, design standard and other factors, firms will save a certain amount of production cost after sharing information, and the unit production cost of manufacturer firm i decreases to c_i. $\eta_i(0<\eta_i<1)$ is the sensitivity coefficient of the unit production cost of the endogenously given manufacturer firm i to the amount of information co-sharing of its own information, $\varphi_{ij}(0<\varphi_{ij}<1, i\neq j)$ is the sensitivity coefficient of the endogenously given manufacturer firm i's unit production cost sensitivity coefficient to the amount of information co-sharing of the acquisition-getting firm j, $\gamma_{ij}(0<\gamma_{ij}<1, i\neq j)$, which denotes the capacity of information co-sharing between the two firms, $\gamma_{ij}=\gamma_{ji}$. Manufacturer firms publish supply information for broadcasting across the network, and different manufacturers are limited by the extent of their blockchain technology applications, thus the amount of information co-sharing is not the same, and the amount of information co-sharing for manufacturer firm i is x_i. The technology cost that manufacturer enterprise i needs to pay in the process of choosing to apply blockchain technology for information collaborative sharing is c_{1i}, the size of which is related to the amount of information collaborative sharing, and $c_{1i}=\beta x_i^2/2$, which is a convex function with respect to x_i, and β is the input technology cost coefficient, blockchain technology innovation inputs and outputs show the law of diminishing marginal returns.

Consider that among n firms in the same hierarchy, there are interactions between firms, and the mutual cooperation or competitive relationship between any two firms will have an impact on the firm's strategy. The inverse demand function for a manufacturer's product in a supply chain network is affected by the amount ordered by homogeneous firms. The price p_i is specified in equation (2):

$$\begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} = \begin{bmatrix} a \\ a \\ \vdots \\ a \end{bmatrix} - b\begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_n \end{bmatrix} - b\begin{bmatrix} q_1 & 0 & \cdots & 0 \\ q_2 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ q_n & 0 & \cdots & 0 \end{bmatrix}\begin{bmatrix} 1 & 1 & \cdots & 1 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 \end{bmatrix}\begin{bmatrix} q_1 & & & \\ & q_2 & & \\ & & \ddots & \\ & & & q_n \end{bmatrix} * \begin{bmatrix} 0 & \lambda_{12} & \cdots & \lambda_{1n} \\ \lambda_{21} & 0 & \cdots & \lambda_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \lambda_{n1} & \lambda_{n2} & \cdots & 0 \end{bmatrix}\begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \tag{2}$$

Considering the effect of including $[q_1\ q_2 \cdots q_n]^T$ as an unknown variable on other manufacturer firms, the sales price of a manufacturer firm can be transformed into equation (3):

$$\begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} = \begin{bmatrix} a \\ a \\ \vdots \\ a \end{bmatrix} - b \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_n \end{bmatrix} - b \begin{bmatrix} 0 & \lambda_{12} & \cdots & \lambda_{1n} \\ \lambda_{21} & 0 & \cdots & \lambda_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \lambda_{n1} & \lambda_{n2} & \cdots & 0 \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_n \end{bmatrix} \tag{3}$$

n enterprises in the same tier, when only considering the impact of any one enterprise on another enterprise, the amount of manufacturer enterprise i information co-sharing is x_i and information co-sharing saves a certain amount of production costs, after participating in the information co-sharing, the production costs of the manufacturer i are c_i as shown in Equation (4):

$$\begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} = \begin{bmatrix} c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn} \end{bmatrix} - \begin{bmatrix} \eta_1 & & & \\ & \eta_2 & & \\ & & \ddots & \\ & & & \eta_n \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} - \begin{bmatrix} x_1 & 0 & \cdots & 0 \\ x_2 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ x_n & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 \end{bmatrix}$$
$$* \begin{bmatrix} x_1 & & & \\ & x_2 & & \\ & & \ddots & \\ & & & x_n \end{bmatrix} * \begin{bmatrix} 0 & \gamma_{12} & \cdots & \gamma_{1n} \\ \gamma_{21} & 0 & \cdots & \gamma_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \gamma_{n1} & \gamma_{n2} & \cdots & 0 \end{bmatrix} \begin{bmatrix} 0 & \varphi_{12} & \cdots & \varphi_{1n} \\ \varphi_{21} & 0 & \cdots & \varphi_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \varphi_{n1} & \varphi_{n2} & \cdots & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \tag{4}$$

Considering the effect of making $[x_1 \quad x_2 \quad \cdots \quad x_n]^T$ an unknown on the manufacturer's production cost, the manufacturer's corporate production cost can be transformed into equation (5):

$$\begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} = \begin{bmatrix} c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn} \end{bmatrix} - \begin{bmatrix} \eta_1 & & & \\ & \eta_2 & & \\ & & \ddots & \\ & & & \eta_n \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} - \begin{bmatrix} 0 & \gamma_{12} & \cdots & \gamma_{1n} \\ \gamma_{21} & 0 & \cdots & \gamma_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \gamma_{n1} & \gamma_{n2} & \cdots & 0 \end{bmatrix}$$
$$* \begin{bmatrix} 0 & \varphi_{12} & \cdots & \varphi_{1n} \\ \varphi_{21} & 0 & \cdots & \varphi_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \varphi_{n1} & \varphi_{n2} & \cdots & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \tag{5}$$

On this basis, the profit functions of the manufacturer and supplier are π_{mi}^l, π_{si}^l, respectively:

$$\pi_{mi}^1 = (p_i - c_i - w_i) * q_i - \frac{1}{2}\beta x_i^2, i = 1, 2 \cdots n \tag{6}$$

$$\pi_{si}^1 = (w_i - c_{si}) * \sum_{i=1}^{n} q_i, i = 1, 2 \cdots n \tag{7}$$

where $A = \begin{vmatrix} q_1 & 0 & \cdots & 0 \\ q_2 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ q_n & 0 & \cdots & 0 \end{vmatrix}, B = \begin{vmatrix} 1 & 1 & \cdots & 1 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 \end{vmatrix}, C = \begin{vmatrix} q_1 & 0 & \cdots & 0 \\ 0 & q_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & q_n \end{vmatrix}$, $S_i = \begin{bmatrix} q_{i+1} & 0 & \cdots & 0 \\ 0 & q_{i+2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & ql \end{bmatrix}, i = 1 \cdots n,$

$K = \begin{bmatrix} 0 & \delta_{12} & \cdots & \delta_{1n} \\ \delta_{21} & 0 & \cdots & \delta_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \delta_{n1} & \delta_{n2} & \cdots & 0 \end{bmatrix} D_i$ are the square matrices whose $n \times n$ main diagonal ripples have numbers, and E is the unit matrix of $n \times n$. Let the number of E's in $F = [E_1 \quad E_2 \quad \cdots \quad E_n]$, F m be affected by the number of firms n and behave as follows:

$$m=\begin{cases}\dfrac{n+1}{2}, n \text{ is odd}\\ \dfrac{n+2}{2}, n \text{ is even}\end{cases} \tag{8}$$

Under this condition, the production cost c_i^* of the manufacturer firm i is expressed as:

$$\begin{bmatrix}c_1\\c_2\\\vdots\\c_n\end{bmatrix}=\begin{bmatrix}c_{m1}\\c_{m2}\\\vdots\\c_{mn}\end{bmatrix}-\begin{bmatrix}\eta_1&&&\\&\eta_2&&\\&&\ddots&\\&&&\eta_n\end{bmatrix}\begin{bmatrix}x_1\\x_2\\\vdots\\x_n\end{bmatrix} -R*B*U*\begin{bmatrix}E_1 & E_2 & \cdots & E_n\end{bmatrix}\begin{bmatrix}V_1&&&\\&V_2&&\\&&\ddots&\\&&&V_n\end{bmatrix}.*M*N\begin{bmatrix}1\\1\\\vdots\\1\end{bmatrix} \tag{9}$$

where $M=\begin{bmatrix}0&\varphi_{12}&\cdots&\varphi_{1n}\\\varphi_{21}&0&\cdots&\varphi_{2n}\\\vdots&\vdots&\ddots&\vdots\\\varphi_{n1}&\varphi_{n2}&\cdots&0\end{bmatrix}$, $N=\begin{bmatrix}0&\gamma_{12}&\cdots&\gamma_{1n}\\\gamma_{21}&0&\cdots&\gamma_{2n}\\\vdots&\vdots&\ddots&\vdots\\\gamma_{n1}&\gamma_{n2}&\cdots&0\end{bmatrix}$ $R=\begin{bmatrix}x_1&0&\cdots&0\\x_2&0&\cdots&0\\\vdots&\vdots&\ddots&\vdots\\x_n&0&\cdots&0\end{bmatrix}$, F_i , $I=\begin{vmatrix}x_1&0&\cdots&0\\0&x_2&\cdots&0\\\vdots&\vdots&\ddots&\vdots\\0&0&\cdots&x_n\end{vmatrix}$, $V_i=\begin{vmatrix}x_{i+1}&0&\cdots&0\\0&x_{i+2}&\cdots&0\\\vdots&\vdots&\ddots&\vdots\\0&0&\cdots&x_i\end{vmatrix}, i=1\cdots n$ are the diagonal matrices with elements on the main diagonal of $n\times n$, and E is the unit matrix of $n\times n$, such that the number m of E in $F=\begin{bmatrix}E_1 & E_2 & \cdots & E_n\end{bmatrix}$, F is affected by the number n of firms, and behaves as above as:

$$m=\begin{cases}\dfrac{n+1}{2}, n \text{ is odd}\\ \dfrac{n+2}{2}, n \text{ is even}\end{cases} \tag{10}$$

The profit functions of the manufacturer and the supplier are π_{mi}^2, π_{si}^2, respectively:

$$\pi_{mi}^2=(p_i^{'}-c_i^{'}-w_i)*q_i-\frac{1}{2}\beta x_i^2, i=1,2\cdots n \tag{11}$$

$$3\pi_{si}^2=(w_i-c_{si})*\sum_{i=1}^{n}q_i, i=1,2\cdots n \tag{12}$$

In the case of multiple firms interacting with each other, the sales price and production cost of firm i will fall again on the basis of the information shared by any two firms as mentioned above, and the size of the sales price as well as the size of the production cost will not go below zero. In this case, the sales price of firm i is p_i^* and the production cost c_i^* and this paper will not construct the size of sales price and production cost of firm i to any other firm in detail for the interaction between three and more than three firms. The magnitude of the interaction between firms on the sales price and production cost of some other firm. In the actual supply operation process, among the n homogeneous enterprises in the same level, the competitive and cooperative relationship between any two enterprises, the interaction of any two combined enterprises on a certain enterprise, and the interaction between any number of enterprises on a certain enterprise will have an impact on the strategies and expected returns of other enterprises, therefore, when considering the impact of the joint inter-enterprise interaction on other enterprises in supply chain network, a manufacturer in the supply chain n has to consider the impact of the inter-enterprise interaction on other enterprises, which will have an impact on the sales price and production cost of a certain manufacturer in the supply chain. When the impact is considered in the supply chain network, the expected profit of a manufacturer i in the supply chain is π_{mi} and the expected profit of a supplier firm i is π_{si} as follows:

$$\pi_{mi}^{n} = (p_i^{n-1} - c_i^{n-1} - w_i) * q_i^i - \frac{1}{2}\beta x_i^2 i = 1,2\cdots n \tag{13}$$

$$\pi_{si}^{n} = (w_i - c_{si}) * \sum_{i=1}^{n} (q_i^1 + q_i^2 + \cdots q_i^i), i = 1,2\cdots n \tag{14}$$

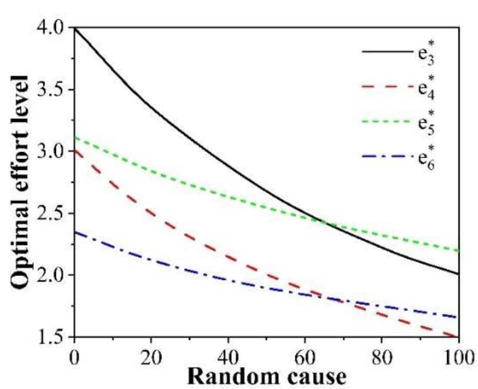
III. Numerical simulation analysis and optimization path

III. A. Numerical simulation analysis

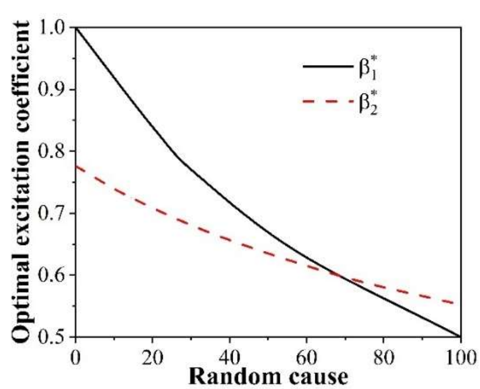
In this section, we simulate the supply chain information sharing model constructed above through numerical arithmetic examples to assess the sensitivity of the relevant parameters and discuss the impact of different parameters on the optimal incentive coefficients of the manufacturer, the optimal level of effort of the supplier's information technology and information environment, as well as the benefits of both parties.

III. A. 1) Parameter setting

Referring to the relevant literature and combining with practical experience to assign values to the relevant parameters, blockchain technology capability coefficient $x = 4$, environmental capability coefficient $y = 3$, blockchain technology cost coefficient $p = 4$, environmental cost coefficient $q = 4$, $\sigma^2 = 8$, risk aversion coefficient of the supplier $\rho = 1$, $\overline{\omega} = 5$, $A = 50$, according to the correlation function calculation can be obtained: (1) when the subsidy is unrestricted, the optimal incentive coefficient of the manufacturer to the supplier is $\beta_1^* = 0.9608$, and the manufacturer's utility expectancy is $E_i(v) = 13.0571$, the optimal level of effort for supplier blockchain technology is $e_3^* = 3.8231$, the optimal level of effort for the blockchain technology environment is $e_4^* = 2.8422$, and the supplier's utility expectation value $E_1(\omega) = 5$. (2) When subsidies are constrained, the manufacturer's optimal incentive coefficient for suppliers is $\beta_2^* = 0.7322$, the manufacturer's utility expectation is $E_2(v) = 12.2119$, and the optimal level of effort for supplier blockchain technology is $e_5^* = 3.0211$, the optimal effort level of the blockchain technology environment is $e_6^* = 2.2783$, and the supplier's utility expectancy $E_2(\omega) = 5$, based on the above initial assignment of the relevant parameters, the subsidy with or without limitations is carried out using the software matlab 2018a two simulation examples to analyze the trend of the manufacturer's incentive effect on suppliers when either parameter is changed.



(a)Optimal effort level



(b)Optimal excitation coefficient

Figure 2: Results of random factor sensitivity analysis

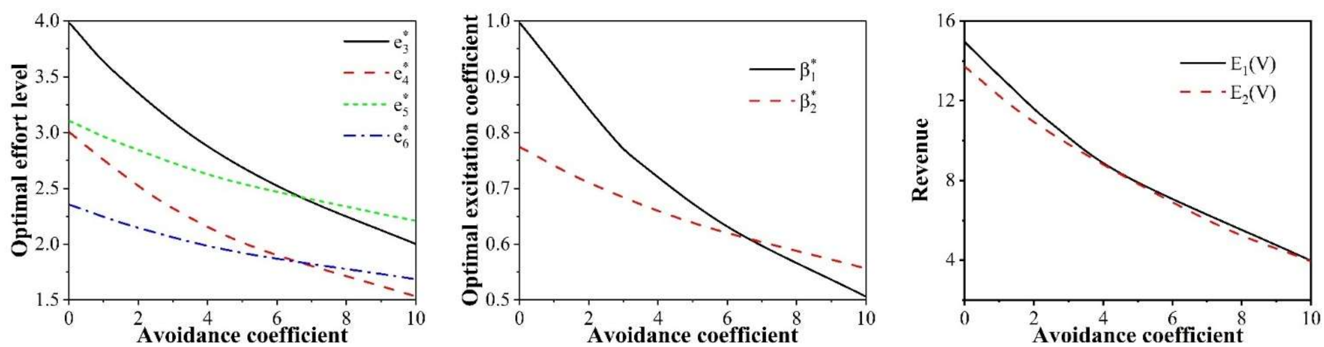
III. A. 2) Simulation and analysis of relevant parameters

(1) Random factor sensitivity analysis

The results of the random factor sensitivity analysis are shown in Figure 2, where (a)~(b) are the supplier optimal effort level and supplier optimal incentive coefficient, respectively. As the random factor variance increases, the manufacturer's optimal incentive coefficient for suppliers and the optimal effort level of supplier information sharing both show a decreasing trend. This indicates that the greater the impact of uncertainty (e.g., market environment fluctuations) in the supply chain sharing model, the more prone to slack behavior and the more detrimental to information sharing behavior.

(2) Sensitivity analysis of suppliers' risk aversion coefficient

The sensitivity analysis of supplier's risk aversion coefficient is shown in Figure 3, where (a)~(c) are the optimal effort level, optimal incentive coefficient, and manufacturer's revenue, respectively. As can be seen from the figure below, as the supplier's risk aversion coefficient increases, the manufacturer's optimal incentive coefficient of the supplier, the manufacturer's utility expectations, and the optimal level of effort of the supplier's information sharing all show a decreasing trend. This indicates that the lower the risk aversion of suppliers, the more unfavorable the information sharing behavior of the supply chain as a whole.

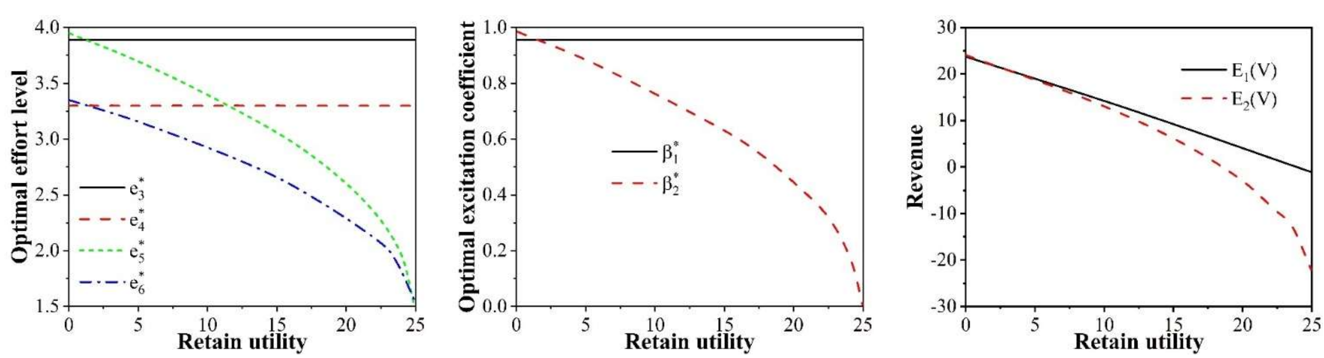


(a)Optimal effort level (b)Excitation coefficient (c)Manufacturer's revenue

Figure 3: Sensitivity analysis of the risk aversion coefficient of suppliers

(3) Supplier retention utility sensitivity analysis

Taking the same method as above, the supplier retention utility sensitivity is explored, and the results of the supplier retention utility sensitivity analysis are shown in Fig. 4. In the case of unrestricted subsidies, the manufacturer's optimal incentive coefficient for suppliers and the subcontractor's optimal effort level are independent of the subcontractor's retention utility, and the general contractor's revenue decreases with the rise of the subcontractor's retention utility; in the case of restricted subsidies, the general contractor's optimal incentive coefficient for subcontractors, the general contractor's revenue, and the subcontractor's optimal effort level all decrease with the rise of the subcontractor's retention utility. This suggests that the higher the retained utility of the subcontractor, the greater the inertia of its information sharing behavior.

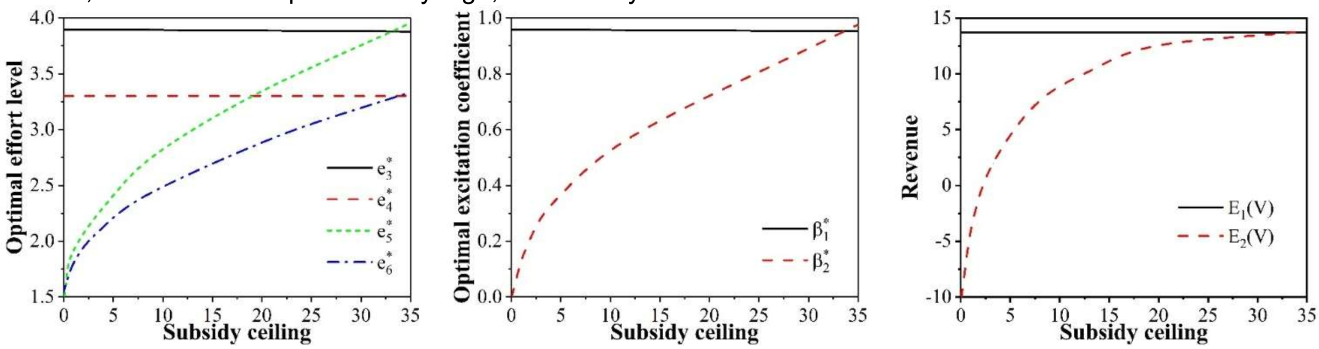


(a)Optimal effort level (b)Excitation coefficient (c)Manufacturer's revenue

Figure 4: Suppliers retain utility sensitivity analysis

(4) Subsidy cap sensitivity analysis of manufacturers to suppliers

With the support of Matlab simulation and analysis software, the sensitivity of manufacturers to suppliers' subsidy cap is explored, and the results of subsidy cap sensitivity analysis are shown in Figure 5. In the case of unrestricted subsidy, the manufacturer's optimal incentive coefficient to suppliers, its own revenue, and the supplier's optimal level of effort are independent of the subsidy cap; in the case of restricted subsidy, the manufacturer's optimal incentive coefficient to suppliers, its own revenue, and the supplier's optimal level of effort are all increased with the increase of the subsidy cap. This suggests that raising the subsidy cap is conducive to promoting information sharing behavior, but when the cap is infinitely high, the subsidy will lose its incentive effect.

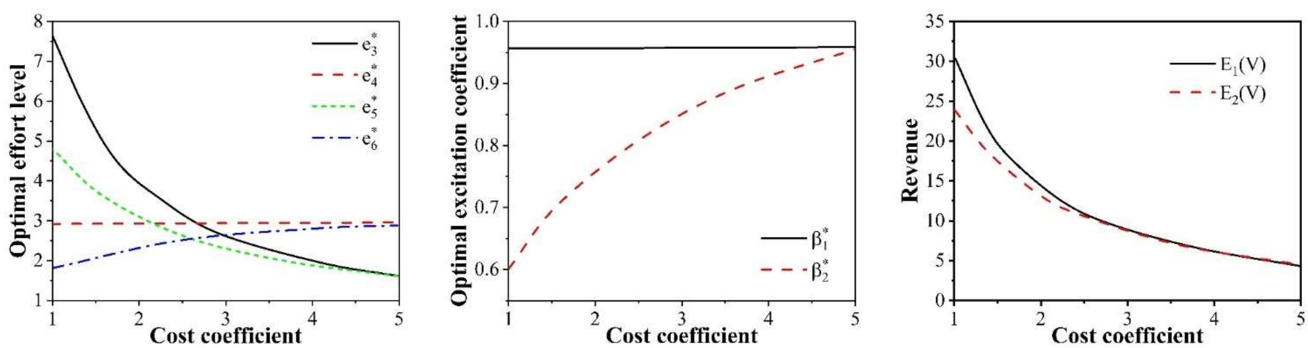


(a)Optimal effort level (b)Excitation coefficient (c)Manufacturer's revenue

Figure 5: Suppliers retain utility sensitivity analysis

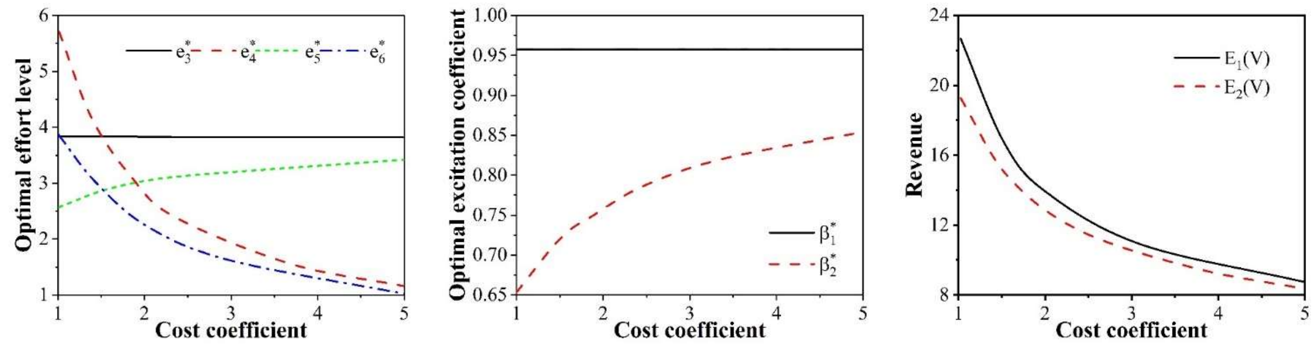
(5) Sensitivity analysis of cost coefficients for the level of supplier information sharing efforts

The cost coefficient of supplier information sharing effort level includes the cost coefficient of blockchain technology effort level and the cost coefficient of information environment effort level. The trend of the impact of the blockchain technology effort level is shown in Figure 6, and the trend of the impact of the environment effort level is shown in Figure 7. In Figure 6, as the cost coefficient of the supplier blockchain technology effort level increases, both the manufacturer revenue and the supplier blockchain technology effort level show a decreasing trend, while the manufacturer's incentive coefficient for the supplier and the supplier information environment effort level show an increasing trend. In Figure 7, as the cost coefficient of supplier information environment effort level increases, the manufacturer revenue and supplier information environment effort level show a decreasing trend, and the manufacturer's incentive coefficient for suppliers and supplier information activity effort level show an increasing trend. This indicates that the higher the cost coefficient of supplier effort level, the less favorable it is to promote information sharing behavior.



(a)Optimal effort level (b)Excitation coefficient (c)Manufacturer's revenue

Figure 6: The level of effort in blockchain technology influences trends

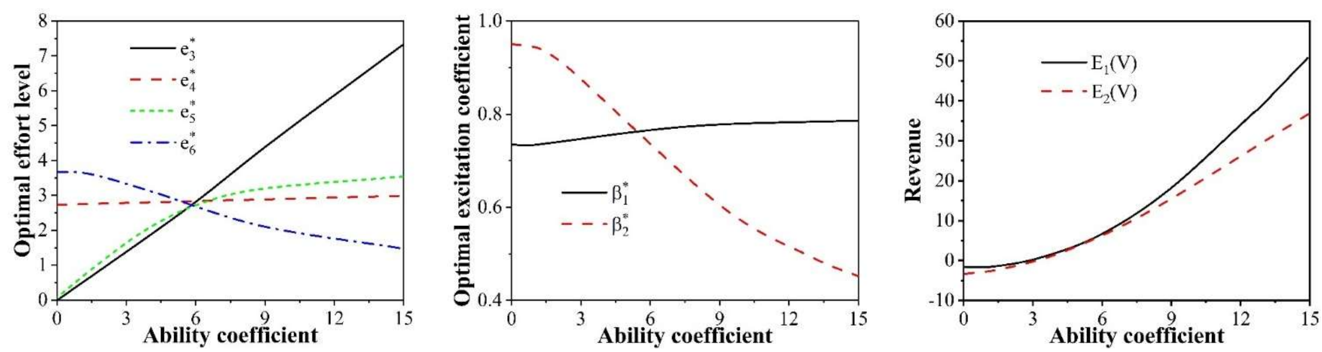


(a)Optimal effort level (b)Excitation coefficient (c)Manufacturer's revenue

Figure 7: The level of environmental effort influences the trend

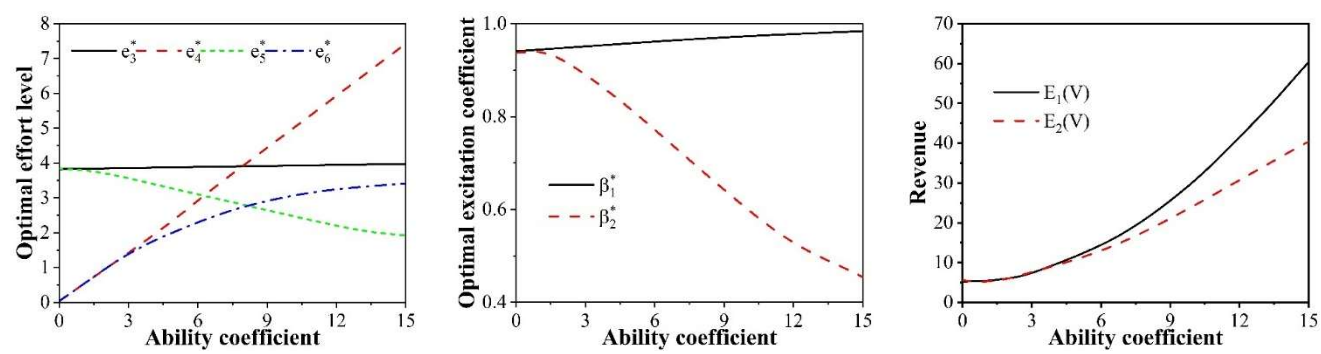
(6) Sensitivity analysis of the capability coefficient of the level of suppliers' information sharing efforts

The capability coefficient of supplier information sharing effort level includes the capability coefficient of blockchain technology effort level and the capability coefficient of information environment effort level. The capability coefficient of blockchain technology effort level is shown in Figure 8, and the trend of the influence of environment capability coefficient is shown in Figure 9. In Figure 8, the optimal incentive coefficient of the manufacturer for the supplier and its own benefit, and the effort level of the supplier's information sharing show an upward trend as the ability coefficient of the supplier's level of effort of blockchain technology increases with the increase of the supplier's level of effort of blockchain technology in the case of subsidy without restriction. In Figure 9, the optimal incentive coefficient of manufacturer to sub-supplier and its own benefit, and the effort level of supplier information sharing show an upward trend with the increase of the ability coefficient of the effort level of supplier information environment in the case of subsidy without restriction.



(a)Optimal effort level (b)Excitation coefficient (c)Manufacturer's revenue

Figure 8: The capability coefficient of the effort level in blockchain technology



(a)Optimal effort level (b)Excitation coefficient (c)Manufacturer's revenue

Figure 9: The influence trend of the environmental capacity coefficient

III. B. Optimizing the path

With the theoretical support of relevant literature and data, it is found that the shared supply chain optimization relying on blockchain has theoretical feasibility, and the analysis of the optimization path of the shared supply chain relying on blockchain has practical needs, so the in-depth analysis of the optimization path has both theoretical support and practical support. Therefore, it is necessary to further analyze the specific path of blockchain-based shared supply chain optimization. In this subsection, based on the above game model and the principles of blockchain technology and the results of numerical simulation analysis of shared supply chain, the specific paths of shared supply chain optimization relying on blockchain are discussed from the aspects of government level and enterprise level. The details are as follows:

III. B. 1) Government level

The government is an important driving force to promote the application of blockchain in shared supply chains, and an important guarantee to facilitate the functioning of blockchain-based shared supply chain optimization paths. The government's efforts for the construction of blockchain-based shared supply chain will provide important support for the realization of the optimization path.

(1) Optimize top-level design and development planning

Blockchain-based shared supply chain construction is a complex project involving many parties, and the smooth implementation of the project requires a perfect top-level design and development plan to guide it, so as to realize the orderly connection of all parties involved and the effective allocation of resources. It is suggested that scientific research institutions, professional associations and leading enterprises should jointly study and formulate the development strategy of shared supply chain relying on blockchain, and discuss the technical research and development, logistics and transportation, and security supervision involved in the application of blockchain in shared supply chain in conjunction with relevant departments.

(2) Strengthen infrastructure and technological innovation

The realization of the optimization path of blockchain-based shared supply chain requires promoting the construction of blockchain-based shared supply chain, while high-quality infrastructure and constantly developing technology are necessary guarantees for the organic combination of blockchain and shared supply chain. At present, it is recommended to focus on the core objective of blockchain-based shared supply chain development, break through the boundaries of shared supply chain subjects and institutional barriers, actively promote the construction of industry-academia-research and application system for combining blockchain and shared supply chain, and improve the agricultural information and technological support system covering the entire shared supply chain, so as to provide infrastructural and technical support for the construction of blockchain-based shared supply chain and to facilitate the realization of the optimization path of blockchain-based shared supply chain. supply chain optimization path is realized.

(3) Improve laws and regulations and regulatory system

The combination of blockchain and shared supply chain involves many legal issues, and it is necessary to improve laws and regulations to make blockchain-based shared supply chain operate in an orderly manner according to the law and provide legal norms for the realization of blockchain-based shared supply chain optimization path.

III. B. 2) Enterprise level

Enterprises are important subjects in the operation of shared supply chain, and they are even more important scenes in the operation of blockchain-based shared supply chain. The support of enterprises is indispensable for promoting the construction of blockchain-based shared supply chain, and it is also a necessary guarantee for the realization of blockchain-based shared supply chain optimization path. The role that can be played by the enterprise level is analyzed below:

(1) Improve the development strategy and collaboration mechanism

Enterprises should actively promote the application of blockchain, should not resist it because it may affect their own information center status, should make clear its important value to the overall development of the shared supply chain and the long-term benefits it can bring to the enterprise, and provide financial support and scenario guarantee for the shared supply chain practice relying on blockchain, so as to provide a possibility for relevant practices. With its influence on the upstream and downstream, it should take measures such as financial incentives to incorporate the upstream and downstream of the shared supply chain into the blockchain system, so as to realize the organic combination of the overall shared supply chain and the blockchain, thus providing information support for the coordinated development of the shared supply chain as a whole, and providing practice scenarios for the realization of the optimization path of the shared supply chain relying on the blockchain.

(2) Utilizing enterprise spirit and innovation ability

Enterprises play an important role in the development of shared supply chain, and entrepreneurs, as the core of the enterprises, play their entrepreneurial spirit, which is of great value to the construction of shared supply chain relying on blockchain. As far as blockchain itself is concerned, it is a new type of information technology, and the application of new technology is usually accompanied by risks, for this reason, it is difficult for individuals such as farmers to become promoters of new technology due to the influence of knowledge and capital and behavioral characteristics, while entrepreneurs should actively take responsibility, dare to try new things, and provide support for the optimization of shared supply chain paths relying on blockchain.

III. B. 3) Optimization path validation analysis

In order to confirm the feasibility of the optimization path above, the enterprise satisfaction as the evaluation standard of the path validation analysis, and the data from the questionnaire scale test, its Liket scale has five dimensions (reliability, responsiveness, agility, security, convenience), 100 enterprises were selected as the sample of this study, and offline questionnaires were distributed to obtain the research data, and the questionnaire validity rate was 100%. The results of the statistical analysis of the enterprise satisfaction of the optimization path are shown in Table 1, in which X1~X5 indicate satisfied, more satisfied, basically satisfied, dissatisfied, and very dissatisfied, respectively. According to the size of the data in the table, 51~60 enterprises are satisfied with the optimization path proposed in this paper, while the number of enterprises with more satisfied attitude is 14~31, and a few enterprises show dissatisfaction with the optimization path. Overall the optimization path proposed in this paper can meet the needs of most enterprises, which greatly confirms the practical application value of the optimization path.

Table 1: Optimize the statistical analysis results of path satisfaction

Dimension	X1	X2	X3	X4	X5
Reliability	60	14	8	10	8
Responsiveness	57	18	7	9	9
Agility	51	31	6	7	5
Safety	53	25	10	7	5
Convenience	58	20	7	7	8

IV. Conclusion

The study constructs a supply chain sharing model and conducts numerical simulation analysis by combining blockchain technology with evolutionary game theory, and obtains three important findings:

Blockchain technology capability enhancement has a significant positive driving effect on supply chain information sharing, and when the capability coefficient of the supplier's blockchain technology effort level increases, the manufacturer's optimal incentive coefficient and benefit to the supplier both tend to increase.

Risk factors have a significant inhibitory effect on information sharing behavior, as the random factor variance increases, the optimal incentive coefficient of the manufacturer to the supplier decreases from 0.89 to 0.61, and the optimal effort level of the supplier's information sharing decreases simultaneously.

The design of incentive mechanism is crucial to promote the implementation of blockchain technology. In the case of subsidy constraints, when the subsidy cap is increased from 0.6 to 0.9, the optimal incentive coefficient of manufacturers to suppliers, as well as their own benefits and the optimal level of suppliers' efforts are significantly increased.

Based on the above conclusions, the government should optimize the top-level design, strengthen the infrastructure, and improve the laws and regulations; the enterprises should improve the development strategy and collaboration mechanism, and give full play to the spirit of enterprise innovation. The validation results of the optimization path show that 60% of enterprises are satisfied in the reliability dimension, which confirms that the proposed path has high practical application value and provides a systematic solution for the strategic implementation of blockchain technology in shared supply chain.

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