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The Game Theory Analysis of Information Sharing for Supply Chain Firms with the use of Blockchain

Supply chains face problems due to a lack of shared information, leading to high inventory costs and inaccurate demand forecasts. This hurts everyone involved and limits the growth of the supply chain. Blockchain technology, with its strengths in sharing information securely and openly, can help solve these problems. This paper studies how blockchain can be used to share information in supply chains and how different participants might choose to share information.

Keywords: Information sharing, Blockchain, Game theory, Supply chain

Introduction

The supply chain is a complex system that connects different companies through information sharing. It controls how products move from manufacturers to customers. The supply chain has problems like high trust costs, disputes over transactions, and information asymmetry. These problems make the supply chain more complex and harder to forecast demand. Blockchain technology (BCT) can help solve these problems because it is decentralized, transparent, traceable, confidential, and immutable. BCT can also improve supply chain partnerships and reduce costs. BCT may provide a solution for sharing information in supply chains, but new management models are needed.

Related Work

Sharing information is when companies that work together exchange data and information. Sharing good information is important for the supply chain to run smoothly and efficiently. Studies show that sharing information can help reduce problems caused by not having the same information, such as making demand more predictable, making orders fill faster, lowering costs, and making the supply chain work better. Other studies have shown that choosing the right information-sharing strategies among members can save money and make more money overall. Comparing the expected amount of money made before and after sharing information about demand and cost, it is concluded that the total amount of money made by the supply chain has increased after information is shared.

Research on the factors that affect information-sharing behaviour shows that how companies share information is affected by factors such as the cost of getting information, the risk of information leaking, changes in the outside world, and how advanced their information technology is. How much extra profit is shared also has some impact on how companies decide to share information. Some studies have concluded that the amount of trust between companies that work together is clearly positively correlated with how much information they share. Additionally, some other studies have collected data from 155 production and service departments to analyse the extent to which how advanced their RFID technology is affects how companies share information. The results show that companies with more advanced RFID technology are more willing to share information.

Use of Blockchain Technology (BCT)

The first famous use of BCT was in finance, where Bitcoin was created. BCT's features make it very secure and efficient for processing transactions. BCT is also being used in other areas, such as supply chain management (SCM). The main difference between using BCT in finance and in SCM is that SCM is more concerned with transparency and being able to track things. BCT can be used to solve problems in SCM in a number of ways:

1. **Information sharing**: BCT can be used to share information securely and privately, which can help to solve problems caused by not having the same information.

2. **Data traceability and qualification:** BCT can be used to track data and make sure it is accurate, which can help to prevent counterfeiting and other problems.

3. **Mutual trust**: BCT can be used to improve trust between companies by making sure that data is accurate and cannot be tampered with supply chains are long, spread out, and complex. Companies in the supply chain typically use centralized systems like ERP, EDI, or Internet/Intranet information integration systems. Blockchain technology has brought new ways to share information in supply chains, mainly in a few areas:

4. **Clearer Data Ownership:** Blockchain technology makes it clear who owns data and encourages companies to share it. In the past, it was hard to separate data ownership and use rights, so companies didn't want to share data. Blockchain timestamps data blocks through a competition, making data on the chain unique. Smart contracts automatically transfer property rights when data is shared between different entities. This ensures that everyone agrees on who owns the data.

5. **Different Levels of Data Sharing Readiness:** Companies upstream and downstream in the supply chain have a reason to share data, but they are not all at the same level of development. Under the digital economy, most supply chain companies have gone through digital transformation and have some basic digital infrastructure. However, their ability to organize and use data is not the same, and the value they get from sharing data and the returns they get are not the same.

6. **Information as a Competitive Advantage:** Information is an intangible asset that is important for making business decisions, and it is a unique resource and competitive advantage. With blockchain technology, the more private information that is shared between upstream and downstream supply chain participants, the greater the risk of information leakage and cooperation spill over for companies. Other participants may take advantage of this by "free-riding."

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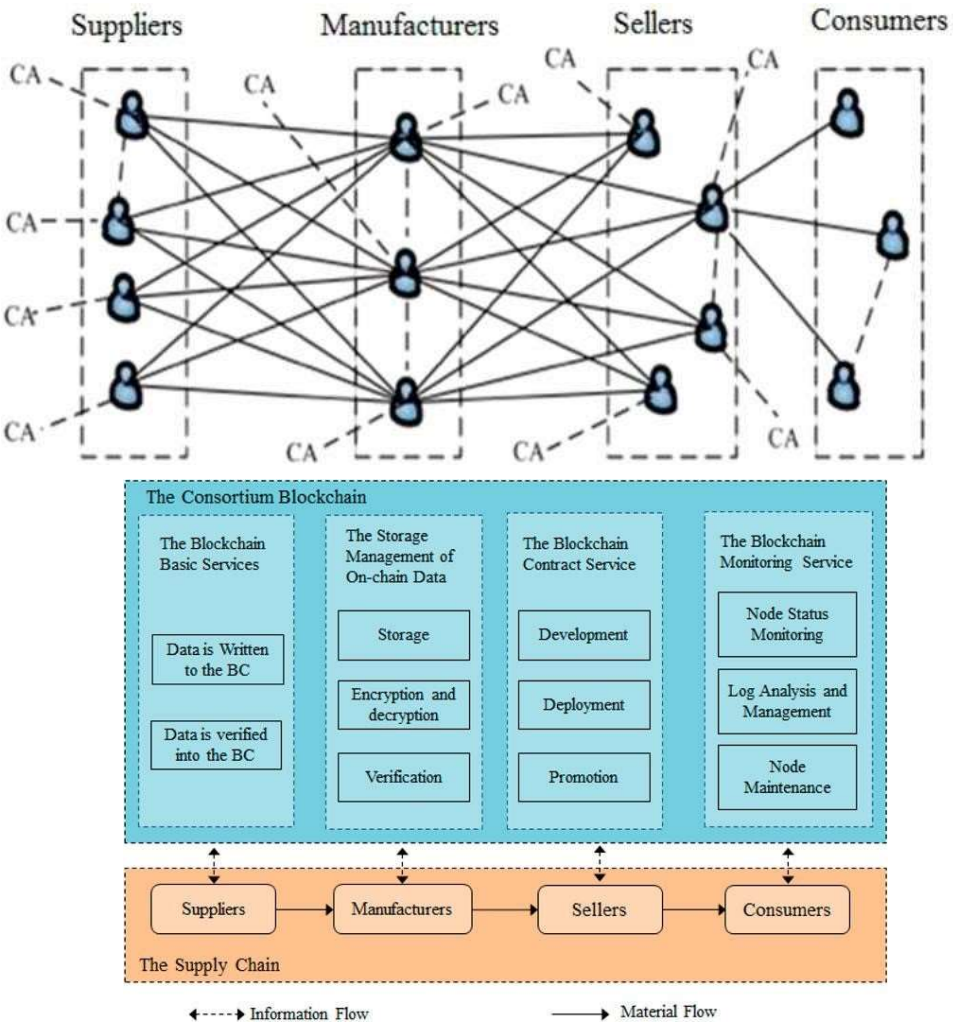
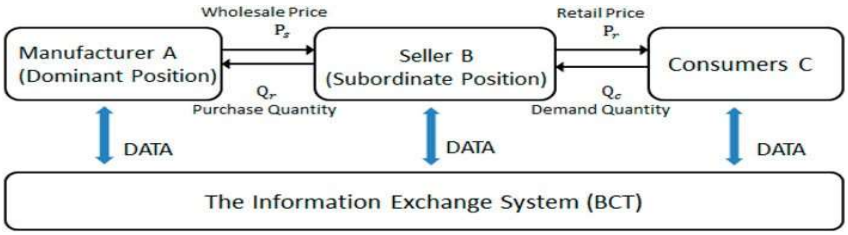
10. **Efficiency:** BCT can be used to automate processes and make them more efficient, which can save time and money (Cui et al., 2015; Apte and Petrovsky, 2016).





Game theory

Evolutionary game theory is a way of studying how people's behavior changes over time. It assumes that people are rational and then analyzes their choices and the outcomes of their interactions. One important concept in evolutionary games is the evolutionarily stable strategy (ESS), which is a state that can be maintained even when there are small changes in the system. Another important concept is replicator dynamics (RD), which is a mathematical model that describes how individuals' strategies change over time. RD can be used to predict how the behavior of individuals in a population will change. Some researchers have used evolutionary game theory to study data sharing.

The Information Sharing Architecture Based on Consortium Blockchain

Information Sharing Architecture based on a Consortium Blockchain (CB) to enhance supply chain coordination. The use of CB addresses challenges in traditional supply chains, providing solutions to opaque information sharing and lack of interaction among nodes.

Key Points:

1. **Blockchain Features Addressing Supply Chain Challenges:**

- The distributed nature of CB resolves geographical dispersion and facilitates transparent data exchange, bringing higher transparency to supply chain collaboration.

- CB's advantages, including distributed data storage, traceability, confidentiality, and immutability, improve data collection, verification, and storage, enhancing decision-making accuracy for market fluctuations.

2. **Enhancing Security and Reliability:**

- The consensus mechanism, encryption algorithm, and immutability of the blockchain ensure secure and reliable data without intermediaries.

- Blockchain minimizes transaction costs, reduces fraud, and unethical issues in supply chain coordination.

3. **Smart Contracts and Traceability Benefits:**

- Smart contracts automate verification and execution of contract terms, improving overall chain efficiency.

- Traceability features enable real-time tracking of commodity routes, aiding in inventory management and reducing errors and costs.

- **The Influencing Factors of Information Sharing Based on Evolutionary Game**

TABLE 2 | Composition of both players' income.

	Manufacturer	Seller
Normal Income	π_s^N	π_r^N
Synergy Benefits	$gk_s\omega_r$	$gk_r\omega_s$
Incentive Benefits	$\alpha\omega_s$	$\alpha\omega_r$
Speculative Returns	$k_s\omega_r$	$k_r\omega_s$
BCT Application Costs	c_s^B	c_r^B
Risk-Taking Costs	$\mu\omega_s$	$\mu\omega_r$

4.1

Assumption 1. In the game, the internal factors such as operating conditions, employee literacy, managerial expertise and organizational structure of each enterprise are different. Therefore, the ability to collect and use information is also different. The coefficient ki is used to reflect the ability to absorb and utilize information.

TABLE 4 | The Manufacturer's evolutionary stability strategies.

Alternative equilibrium solutions	Prerequisites		Evolutionary stability strategy
$x_1^* = 0\ x_2^* = 1\ y^* = \frac{c_s^B + \mu\omega_s}{(g-1)k_s\omega_r + \alpha\omega_s}$	$y \neq y^*$	$y = y^*$	$x_1^* = 0,\ x_2^* = 1$
		$y^* > 1,\ 0 \le y \le 1$	$x_1^* = 0$
		$y^* \le 1,\ 0 \le y < y^*$	$x_1^* = 0$
		$y^* \le 1,\ y^* < y \le 1$	$x_2^* = 1$

Assumption 2. While information sharing brings additional benefits to enterprises, it also calls into demand certain costs. cB is used to represent the application costs of BCT that members need to invest in the game.

Assumption 3. When companies share their own private information, various potential risks will arise, such as business information leakage, moral hazards, etc., which will in turn affect their revenues

(Jeong and Hong, 2019). μ is used to represent the risk-taking coefficient when sharing information. The notations involved in game modelling are listed in Table 1.

Static Analysis of Evolutionary Stability Strategies

In this game model, manufacturers and sellers are independent players. Replicated dynamic equations are formulated to obtain their respective optional evolutionary stability strategies.

Proposition 1. The replicated dynamic equation for the manufacturer to choose the sharing strategy is as follows:

$$F_x = \frac{d_x}{d_t} = x(1-x)\{y[(g-1)k_s\omega_r + \alpha\omega_s] - c_s^B - \mu\omega_s\} \quad (1)$$

The following three equilibrium solutions can be obtained by setting F_x to zero:

$$x_1^* = 0$$
$$x_2^* = 1$$
$$y^* = \frac{c_s^B + \mu\omega_s}{(g-1)k_s\omega_r + \alpha\omega_s}$$

Proof of Proposition 1 According to the pay-off matrix (see Tables 2,3), it is calculated that the expected benefits of sharing strategy adopted by the manufacturer is:

$$U_{S1} = y(\pi_s^N + gk_s\omega_r + \alpha\omega_s - c_s^B - \mu\omega_s) + (1-y)(\pi_s^N - c_s^B - \mu\omega_s) \quad (2)$$

The expected benefits of non-sharing strategy is as follows:

$$U_{S2} = y(\pi_s^N + k_s\omega_r) + (1-y)\pi_s^N \quad (3)$$

Second, the average expected benefits adopted by the manufacturer is as follows:

$$\overline{U_S} = xU_{S1} + (1-x)U_{S2} \quad (4)$$

Next, the replicated dynamic equation for the manufacturer to choose the sharing strategy is as follows:

TABLE 3 | The pay-off matrix of both players.

Strategy portfolio		Manufacturer	
		The Probability of Sharing Strategy is x	The Probability of Non-sharing Strategy is 1 − x
Seller	The probability of sharing strategy is y	$(\pi_r^N + gk_r\omega_s + \alpha\omega_r - c_r^B - \mu\omega_r, \pi_s^N + gk_s\omega_r + \alpha\omega_s - c_s^B - \mu\omega_s)$	$(\pi_r^N - c_r^B - \mu\omega_r, \pi_s^N + k_s\omega_r)$
	The probability of non-sharing strategy is $1-y$	$(\pi_r^N + k_r\omega_s, \pi_s^N - c_s^B - \mu\omega_s)$	(π_s^N, π_r^N)

TABLE 5 | The Seller's evolutionary stability strategies.

Alternative equilibrium solutions	Prerequisites		Evolutionary stability strategy
$y_1^* = 0\ y_2^* = 1\ x^* = \frac{c_s^B + \mu\omega_s}{(g-1)k_s\omega_r + \alpha\omega_s}$	$x \neq x^*$	$x = x^*$	$y_1^* = 0,\ y_2^* = 1$
		$x^* > 1,\ 0 \le x \le 1$	$y_1^* = 0$
		$x^* \le 1,\ 0 \le x < x^*$	$y_1^* = 0$
		$x^* \le 1,\ x^* < x \le 1$	$y_2^* = 1$

TABLE 6 | The evolutionary stable points in four situations.

Evolution situations		Manufacturer	
		$y^* > 1$	$y^* \le 1$
Seller	$x^* > 1$	① (0, 0)	③ (0, 1)
	$x^* \le 1$	② (1, 0)	④ (0, 0), (1, 1)

$$F_x = \frac{d_x}{d_t} = x\left(U_{S1} - \overline{U_S}\right) = x(1-x)(U_{S1} - U_{S2}) \quad (5)$$

Finally, substitute Eq. 2, Eq. 3, and Eq. 4 into Eq. 5 to get the final replicated dynamic equation.

Proposition 2. The replicated dynamic equation for the seller to choose the sharing strategy is as follow:

$$F_y = \frac{d_y}{d_t} = y(1-y)\{x[(g-1)k_r\omega_s + \alpha\omega_r] - c_r^B - \mu\omega_r\} \quad (6)$$

$$y_1^* = 0$$

$$y_2^* = 1$$

$$x^* = \frac{c_r^B + \mu\omega_r}{(g-1)k_r\omega_s + \alpha\omega_r}$$

The following three equilibrium solutions can be obtained by setting Fy to zero. The detailed argumentation is omitted, as it is similar to that of Proposition 1. Based on the stability axioms of differential equations, it is concluded that when such conditions are satisfied as the first derivative Fx dx dt 0, Fy dy dt 0 and the second derivative F′ x < 0, F′ x < 0, the equilibrium solutions are dynamic evolutionary stability strategies in a stable state. Therefore, the replicated dynamic equations for the derivatives are as follows:

$$F_x' = (1-2x)\{y[(g-1)k_s\omega_r + \alpha\omega_s] - c_s^B - \mu\omega_s\} \quad (7)$$

$$F_y' = (1-2y)\{x[(g-1)k_r\omega_s + \alpha\omega_r] - c_r^B - \mu\omega_r\} \quad (8)$$

Finally, the corresponding dynamic evolutionary stability strategies can be found, which is shown in Table 4 and Table.

CONCLUSION

With the rapid development of information technologies in the Internet era, market competition has evolved into competition among supply chains. In order to improve the responsiveness of supply chains to market demand, reduce costs, and enhance efficiency, it is necessary to realize information sharing among the nodes on the supply chain. . To achieve the above objective, we use evolutionary game theory to studies the change of supply chain members' choice of information sharing, analyzes the strategy shifts between participating companies by using replicated dynamic equations and phase diagrams, and discusses specific effects of six influencing factors on information sharing. In future, we plan to implement a complete platform for information exchange on the supply chain based on the emerging blockchain technology.