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Blockchain-based tripartite evolutionary game study of manufacturing capacity sharing

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A B S T R A C T

In the context of the new round of manufacturing innovation, the sharing economy drives the transformation of manufacturing industry to accelerate the integration and development. However, there are some problems in the process of manufacturing capacity sharing, such as information privacy and security, and difficulty in tracing the sharing process, etc. The application of blockchain technology can effectively solve these problems. To explore the capacity sharing behaviour of manufacturing enterprises from the perspective of blockchain, the article combines evolutionary game theory and constructs a tripartite game model of manufacturing capacity sharing. The replication dynamics and evolutionary stability of the model are analysed using evolutionary game theory, and numerical simulations are carried out using MATLAB software to analyse the impact of parameter changes on the evolutionary outcome. The research results show that the incentive and penalty coefficients under blockchain technology have a facilitating effect on enterprises to carry out sharing, and the enhancement of reputation gain coefficient and loss can promote positive services on the platform.

A R T I C L E I N F O

Keywords:
Blockchain;
Manufacturing;
Capacity sharing;
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MATLAB

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1. Introduction

With the development of the Internet of Things, big data, artificial intelligence and a new round of manufacturing reform, the sharing economy has driven the transformation of the manufacturing industry to accelerate its development and provided a transformation direction for the manufacturing industry [1-5]. Manufacturing capacity sharing is an important element in deepening the integration and development of manufacturing and the Internet, with broad development prospects, and it is particularly important to realize the sustainable development of manufacturing capacity sharing.

The imbalance between supply and demand in manufacturing capacity is a common problem in the market, and capacity sharing can alleviate the mismatch between supply and demand [6]. Capacity sharing can only be achieved by "the platform, the companies that demand manufacturing capacity and the companies that own the manufacturing capacity". The strategic choices of platforms and enterprises play an important role in the capacity utilisation of the manufacturing industry and the development of the economy [7, 8]. However, in the process of manufacturing capacity sharing operation, there will be some problems, such as information privacy and security, the sharing process is difficult to trace and transaction supervision difficulties. Blockchain is the underlying technology for many digital cryptocurrencies, and its features such as decentralisation, open ledger, hashing algorithm, and asymmetric encryption [9, 10] can avoid the risk of information leakage during transactions and make them more secure. These features of blockchain coincide with the demand problems that exist in manufacturing capacity sharing, which can improve the efficiency of the platform and effectively solve the problems that exist in the sharing platform [11, 12].

In previous research, some scholars have applied games to production control on the shop floor to effectively deal with production control problems involving multiple production lines or production goals [13]. Xiao M and Tian Z Y proposed a framework for cloud manufacturing capacity sharing based on a cooperative game algorithm and using MATLAB to analyse the evolutionary outcome [14]. Some scholars have applied blockchain technology to agricultural supply chains, supply chain management, and the financial industry [15-18], but in the manufacturing industry it is mostly applied to manufacturing supply chains, industry 4.0 sustainability, and SCQM [19-21], and few scholars have applied blockchain technology to manufacturing capacity sharing.

Accordingly, the article will combine the characteristics of blockchain to construct a blockchain-based manufacturing capacity sharing model and use evolutionary games to study the capacity sharing behaviour of the manufacturing industry in the blockchain environment.

2. Blockchain-based tripartite evolutionary game analysis of manufacturing capacity sharing

2.1 Main principles of blockchain technology

(1) Distributed ledger technology. A data storage technology is a decentralised distributed database. The data in distributed ledger technology is shared, replicated, and synchronized among the nodes, and it records the transactions between the nodes without the involvement of third parties. Each piece of data in a distributed ledger is signed with a complete and unique timestamp and digital cryptography and cannot be tampered with.
(2) Asymmetric encryption. Asymmetric encryption refers to the encryption of data using different ciphers, i.e. a public key and a private key. Blockchain uses asymmetric encryption algorithms to improve the reliability of data. The public key is a cipher that everyone knows and can be used to encrypt data information, while the private key is a cipher used to decrypt data information and only the recipient of the data information has the private key.
(3) Smart contracts. A smart contract is essentially a program whose content is infinitely scalable and is fully distributed. If both or more parties to the contract meet the triggering conditions, the contract will be automatically triggered and irrevocable, and the execution of the contract will be published to the whole network, with all information immutable, i.e. the transaction is traceable, transparent and irreversible.

2.2 Problem analysis

As shown in the left diagram of Fig. 1., without blockchain technology, enterprises need to publish their information to the platform, and then the platform will match the enterprises for transactions, and the symmetry and openness of information between the two enterprises in the transaction matching process are relatively low, and there is a risk of information privacy being leaked. In the right figure, when blockchain technology is introduced, the decentralized feature of blockchain can reduce the role of platform domination, and the information symmetry and openness between the two sides of enterprises in the transaction matching process is higher, which avoids privacy leakage and improves sharing efficiency [22, 23].

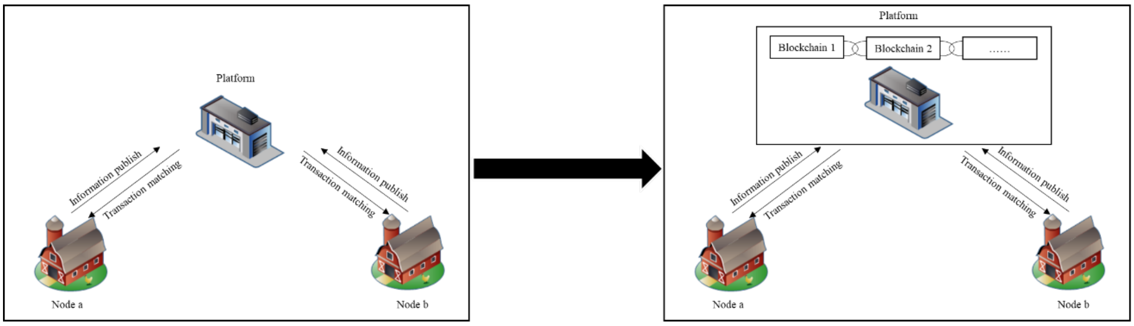

Fig. 1 Before and after introducing blockchain technology

2.3 Coupling analysis of blockchain manufacturing capacity sharing

Coupling analysis refers to the process of considering the interaction or cross-influence of multiple disciplines in a finite analysis. The article constructs a blockchain-based manufacturing capacity sharing model as a fusion innovation for the development of traditional manufacturing capacity sharing platform model, and conducts a coupling analysis between blockchain and manufacturing capacity sharing from three aspects: resource utilization, data trust, and benefit optimization, as shown in Fig. 2.

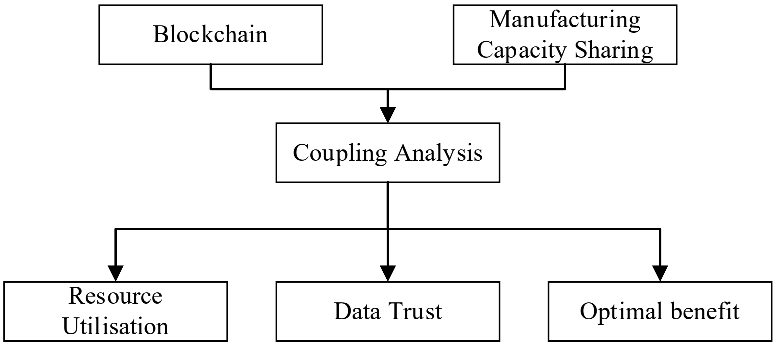

Fig. 2 Analysis of the coupling of blockchain and manufacturing capacity sharing

(1) The coupling of blockchain and manufacturing capacity sharing resource utilization. The capacity provider uploads the redundant capacity information to the platform, and the capacity demander can seek the capacity they need from the platform to maximize resource utilization. The platform data under blockchain technology are all public, and all nodes can query information through the public interface.

(2) The coupling of blockchain and manufacturing capacity sharing data trust. Blockchain technology uses consensus-based specifications and protocols (e.g., open and transparent algorithms) to allow all nodes of the system to exchange data freely and securely in a trusted environment, shifting from trust in the "enterprise" to trust in the "technology".

(3) Optimization of the coupling benefits of blockchain and manufacturing capacity sharing. The purpose of manufacturing capacity sharing is to maximize the utilization of equipment, machines, etc. by integrating and allocating unused capacity. The demanders of capacity can use the capacity, while the providers of capacity can gain revenue and the platform can gain reputation through good service to achieve the best overall benefits for all three parties. One of the features of blockchain is decentralization, where each node is independent and nodes interact with each other without paying additional fees, thus increasing the overall benefits.

2.4 Model assumptions and construction

The article uses evolutionary game theory to investigate the capacity sharing behaviour of manufacturing firms from a blockchain perspective, with each assumption as follows.

Assumption 1. In the game of manufacturing capacity sharing behaviour, there are three nodes of interest, ownership of the capacity, demand for the capacity and the platform of the participant.

Assumption 2. All three nodes have two possible strategies, and will continuously adjust their strategies according to the gains and losses they obtain. Node a has a strategy space of $a = (a_1, a_2)$ = (shared, unshared) and chooses a_1 with probability x and a_2 with probability $(1 - x)$. Node b has a strategy space of $b = (b_1, b_2)$ = (shared, unshared) and chooses b_1 with probability y and b_2 with probability $(1 - y)$. Platform o has a strategy space of $o = (o_1, o_2)$ = (active service , negative service), with probability z of choosing o_1 and probability $(1 - z)$ of choosing o_2 where, $0 \leq x, y, z \leq 1$.

Assumption 3. When only one party shares, the sharing party pays the corresponding cost C_j, but the digitization level of its enterprise is also improved; the digitization level coefficient d, which brings the benefit e_j, then the digitization benefit obtained by the enterprise is de_j [24]. The manufacturing alliance nodes under blockchain technology have an incentive coefficient m for the sharing party and a penalty coefficient n for the non-sharing party.

Assumption 4. When both nodes share, they receive additional synergy gains under blockchain technology with a synergy gain coefficient θ; the number of shared enterprises is Q_j, and quantifying the capacity sharing level of enterprises [25], the sharing level is G_j. When both nodes do not share, the base gain of enterprises is R_j.

Assumption 5. The horizontal revenue coefficient of the platform under blockchain technology is R_hh when the platform is actively serving, and R_l when it is negatively serving, and $R_h > R_l$. The fixed cost of the platform is C_h when it is actively serving, and C_l when it is negatively serving, and $C_h > C_l$. The platform will bring good reputation revenue for itself when it is actively serving, and the revenue coefficient The probability of matching AB when the firm shares both AB when serving positively is K_hh, the probability of matching AB when serving negatively is K_l, and $K_h > K_l$.

Constructing a revenue matrix is in Table 1:

Table 1 Game payoff matrix

	Node a shares x		Node a does not share $1 - x$	
	Node b shares y	Node b does not share $1 - yz$	Node b shares y	Node b does not share $1 - y$
Node o active service z	$(R_h + F_h)(Q_a + Q_b) - C_h$ $de_a - C_a + mG_a + \theta K_h G_a$ $de_b - C_b + mG_b + \theta K_h G_b$	$(R_h + F_h)Q_a - C_h$ $de_a - C_a + mG_a$ $R_b - nG_a$	$(R_h + F_h)Q_b - C_h$ $R_a - nG_b$ $de_b - C_b + mG_b$	$-C_h$ R_a R_b
Node o negative service 1-z	$(R_l - F_l)(Q_a + Q_b) - C_l$ $de_a - C_a + mG_a + \theta K_l G_a$ $de_b - C_b + mG_b + \theta K_l G_b$	$(R_l - F_l)Q_a - C_l$ $de_a - C_a + mG_a$ $R_b - nG_a$	$(R_l - F_l)Q_b - C_l$ $R_a - nG_b$ $de_b - C_b + mG_b$	$-C_l$ R_a R_b

3. Model analysis

3.1 Analysis of replication dynamics and evolutionary stabilization strategies for node *a*

Based on the gain matrix in the table above, the gains when node a is shared and when it is not shared can be derived as:

$$\begin{aligned} U_{a_1} = yz(de_a - C_a + mG_a + \theta K_h G_a) + y(1-z)(de_a - C_a + mG_a + \theta K_l G_a) \\ + z(1-y)(de_a - C_a + mG_a) + (1-y)(1-z)(de_a - C_a + mG_a) \end{aligned} \tag{1}$$

$$U_{a_2} = yz(R_a - nG_b) + y(1-z)(R_a - nG_b) + z(1-y)R_a + (1-y)(1-z)R_a \tag{2}$$

Therefore, the average expected return of node a and the replication dynamic equation are:

$$U_a = xU_{a_1} + (1-x)U_{a_2} \tag{3}$$

$$\begin{aligned} F(x) = \frac{dx}{dt} = x\big(U_a - U_{a_1}\big) = x(1-x)\big(U_{a_1} - U_{a_2}\big) \\ = x(1-x)[yz\theta G_a(K_h - K_l) + y\theta K_l G_a + ynG_b + de_a - C_a + mG_a - R_a] \end{aligned} \tag{4}$$

The evolutionary strategy of node a must satisfy $F(x) = 0$ and $F'(x) < 0$. For $F(x) = 0$, the solution is $x^* = 0$, $x^* = 1$ and $z^* = \frac{C_a - de_a + R_a - mG_a - y\theta K_l G_a - ynG_b}{y\theta G_a(K_h - K_l)}$. $F'(x) = (1-2x)[yz\theta G_a(K_h -$

$K_l) + y\theta K_l G_a + ynG_b + de_a - C_a + mG_a - R_a]$, make $S(y) = yz\theta G_a(K_h - K_l) + y\theta K_l G_a + ynG_b + de_a - C_a + mG_a - R_a$. Since $S'(y) > 0$, $S(y)$ is an increasing function with respect to y. Therefore, when $z = z^*$, $S(y) = 0$, at which point $F'(x) = 0$, no stable strategy can be determined; when $z < z^*$, $S(y) < 0$, at which point $x = 0$ satisfies the stability condition; when $z > z^*$, $S(y) > 0$, at which point $x = 1$ is ESS, satisfying the stability condition, and the evolutionary phase diagram is shown in Fig. 3.

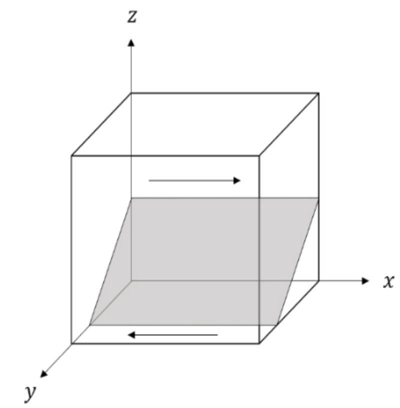

Fig. 3 Digital phase diagrams of node a

3.2 Analysis of replication dynamics and evolutionary stabilization strategies for node *b*

The gains when node b is shared versus not shared are:

$$U_{b_1} = xz(de_b - C_b + mG_b + \theta K_h G_b) + x(1-z)(de_b - C_b + mG_b + \theta K_l G_b) + z(1-x)(de_b - C_b + mG_b) + (1-x)(1-z)(de_b - C_b + mG_b) \quad (5)$$

$$U_{b_2} = xz(R_b - nG_a) + x(1-z)(R_b - nG_a) + z(1-x)R_b + (1-x)(1-z)R_b \quad (6)$$

Therefore, the average expected return of node b and the replication dynamic equation are:

$$U_b = yU_{b_1} + (1-y)U_{b_2} \quad (7)$$

$$F(y) = \frac{dy}{dt} = y(U_b - U_{b_1}) = y(1-y)(U_{b_1} - U_{b_2}) = y(1-y)[xz\theta G_b(K_h - K_l) + x\theta K_l G_b + xnG_a + de_b - C_b + mG_b - R_b] \quad (8)$$

The evolutionary strategy of node b must satisfy $F(y) = 0$ and $F'(y) < 0$. For $F(y) = 0$, the solution is$y^* = 0$, $y^* = 1$ and $z^* = \frac{C_b - de_b + R_b - mG_b - x\theta K_l G_b - xnG_a}{x\theta G_b(K_h - K_l)}$. $F'(y) = (1-2y)[z\theta G_b(K_h - K_l) + x\theta K_l G_b + xnG_a + de_b - C_b + mG_b - R_b]$, make $S(x) = z\theta G_b(K_h - K_l) + x\theta K_l G_b + xnG_a + de_b - C_b + mG_b - R_b$. Since $S'(x) > 0$, $S(x)$ is an increasing function with respect to x. Therefore, when $z = z^*$, $S(x) = 0$, at which point $F'(y) = 0$, no stable strategy can be determined; when $z < z^*$, $S(x) < 0$, at which point $y = 0$ satisfies the stability condition; when $z > z^*$, $S(x) > 0$, at which point $y = 1$ is ESS, satisfying the stability condition, and the evolutionary phase diagram is shown in Fig. 4.

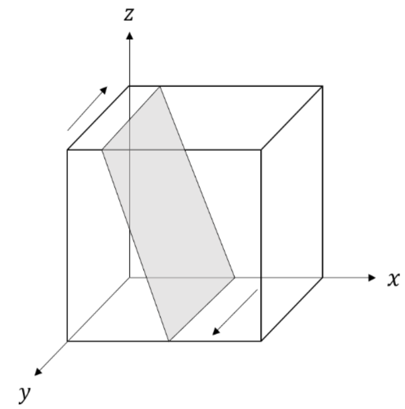

Fig. 4 Digital phase diagrams of node b

3.3 Analysis of replication dynamics and evolutionary stabilization strategies for node *c*

The gains when node o is shared versus not shared are:

$$U_{o_1} = xy[(R_h + F_h)(Q_a + Q_b) - C_h] + x(1-y)[(R_h + F_h)Q_a - C_h] + y(1-x)[(R_h + F_h)Q_b - C_h] + (1-x)(1-y)(-C_h) \tag{9}$$

$$U_{o_2} = xy[(R_l - F_l)(Q_a + Q_b) - C_l] + x(1-y)[(R_l - F_l)Q_a - C_l] + y(1-x)[(R_l - F_l)Q_b - C_l] + (1-x)(1-y)(-C_l) \tag{10}$$

Therefore, the average expected return of node o and the replication dynamic equation are:

$$U_o = zU_{o_1} + (1-z)U_{o_2} \tag{11}$$

$$F(z) = \frac{dz}{dt} = z\left(U_o - U_{o_1}\right) = z(1-z)\left(U_{o_1} - U_{o_2}\right) = z(1-z)[xQ_a(R_h + F_h - R_l + F_l) + yQ_b(R_h + F_h - R_l + F_l) - C_h + C_l] \tag{12}$$

The evolutionary strategy of node o must satisfy $F(z) = 0$ and $F'(z) < 0$. For $F(z) = 0$, the solution is $z^* = 0$, $z^* = 1$ and $x^* = \frac{C_h - C_l - yQ_b(R_h + F_h - R_l + F_l)}{Q_a(R_h + F_h - R_l + F_l)}$. $F'(z) = (1-2z)[xQ_a(R_h + F_h - R_l + F_l) + yQ_b(R_h + F_h - R_l + F_l) - C_h + C_l]$, make $S(y) = xQ_a(R_h + F_h - R_l + F_l) + yQ_b(R_h + F_h - R_l + F_l) - C_h + C_l$. Since $S'(y) > 0$, $S(y)$ is an increasing function with respect to y. Therefore, when $x = x^*$, $S(y) = 0$, at which point $F'(z) = 0$, no stable strategy can be determined; when $x < x^*$, $S(y) < 0$, at which point $z = 0$ satisfies the stability condition; when $x > x^*$, $S(y) > 0$, at which point $z = 1$ is ESS, satisfying the stability condition, and the evolutionary phase diagram is shown in Fig. 5.

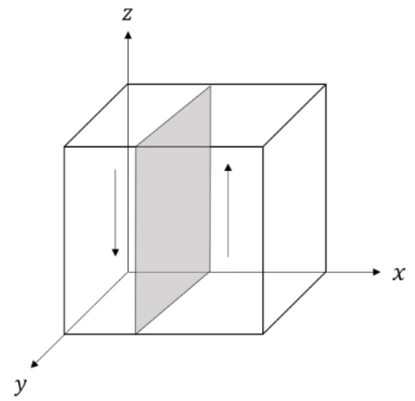

Fig. 5 Digital phase diagrams of node *o*

4. Stability analysis of the equilibrium point of a tripartite evolutionary game system

Letting the replicated dynamic equations equal zero, it is known that there are the following system equilibria E1(0,0,0), E2(0,0,1), E3(0,1,0), E4(0,1,1), E5(1,0,0), E6(1,0,1), E7(1,1,0) and E8(1,1,1), where the Jacobian matrix of the tripartite evolutionary game system is

$$J = \begin{bmatrix} J_1 & J_2 & J_3 \\ J_4 & J_5 & J_6 \\ J_7 & J_8 & J_9 \end{bmatrix} = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix}$$

$$J_1 = (1-2x)[yz\theta G_a(K_h - K_l) + y\theta K_l G_a + ynG_b + de_a - C_a + mG_a - R_a]$$

$$J_2 = x(1-x)[z\theta G_a(K_h - K_l) + \theta K_l G_a + nG_b]$$

$$J_3 = x(1-x)[y\theta G_a(K_h - K_l)]$$

$J_4 = y(1-y)[z\theta G_b(K_h - K_l) + \theta K_l G_b + nG_a]$
$J_5 = (1-2y)[xz\theta G_b(K_h - K_l) + x\theta K_l G_b + xnG_a + de_b - C_b + mG_b - R_b]$
$J_6 = y(1-y)[x\theta G_b(K_h - K_l)]$
$J_7 = z(1-z)[Q_a(R_h + F_h - R_l + F_l)]$
$J_8 = z(1-z)[R_b(R_h + F_h - R_l + F_l)]$
$J_9 = (1-2z)[xQ_a(R_h + F_h - R_l + F_l) + yQ_b(R_h + F_h - R_l + F_l) - C_h + C_l]$

Using Lyapunov first method, the stability of each equilibrium point is analysed as shown [26].

Table 2 Equilibrium point analysis

Equilibrium point	λ1, λ2, λ3	Symbol	Equilibrium results
E1(0,0,0)	$de_a - C_a + mG_a - R_a$, $de_b - C_b + mG_b - R_b$, $-C_h + C_l$	(-,-,-)	ESS
E2(0,0,1)	$de_a - C_a + mG_a - R_a$, $de_b - C_b + mG_b - R_b$, $(-1)(-C_h + C_l)$	(-,-,+)	Unstable
E3(0,1,0)	$\theta K_l G_a + nG_b + de_a - C_a + mG_a - R_a$, $(-1)(de_b - C_b + mG_b - R_b)$, $Q_b(R_h + F_h - R_l + F_l) - C_h + C_l$	(?,+,?)	Unstable
E4(0,1,1)	$\theta G_a(K_h - K_l) + \theta K_l G_a + nG_b + de_a - C_a + mG_a - R_a$, $(-1)(de_b - C_b + mG_b - R_b)$, $(-1)[Q_b(R_h + F_h - R_l + F_l) - C_h + C_l]$	(?,+,?)	Unstable
E5(1,0,0)	$(-1)(de_a - C_a + mG_a - R_a)$, $\theta K_l G_b + nG_a + de_b - C_b + mG_b - R_b$, $Q_a(R_h + F_h - R_l + F_l) - C_h + C_l$	(+,?,?)	Unstable
E6(1,0,1)	$(-1)(de_a - C_a + mG_a - R_a)$, $\theta G_b(K_h - K_l) + \theta K_l G_b + nG_a + de_b - C_b + mG_b - R_b$, $(-1)[Q_a(R_h + F_h - R_l + F_l) - C_h + C_l]$	(+,?,?)	Unstable
E7(1,1,0)	$(-1)(\theta K_l G_a + nG_b + de_a - C_a + mG_a - R_a)$, $(-1)(\theta K_l G_b + nG_a + de_b - C_b + mG_b - R_b)$, $Q_a(R_h + F_h - R_l + F_l) + Q_b(R_h + F_h - R_l + F_l) - C_h + C_l$	(?,?,?)	Unstable
E8(1,1,1)	$(-1)(\theta G_a K_h + nG_b + de_a - C_a + mG_a - R_a)$, $(-1)(\theta G_b K_h + nG_a + de_b - C_b + mG_b - R_b)$, $(-1)[Q_a(R_h + F_h - R_l + F_l) + Q_b(R_h + F_h - R_l + F_l) - C_h + C_l]$	(?,?,?)	Unstable

(1) E1(0,0,0): λ1= $de_a - C_a + mG_a - R_a$, λ2= $de_b - C_b + mG_b - R_b$, λ3=$-C_h + C_l$.

Scenario 1: $de_a - C_a + mG_a < R_a$, $de_b - C_b + mG_b < R_b$, $C_l < C_h$. Then for nodes a and b, the benefit when only one node shares is less than the benefit when neither node shares; when neither node shares, the cost of negative platform service is less than the cost of positive platform service. At this point *λ1, λ2* and *λ3* are all less than zero, and the point is the ESS stability point.

(2) E7(1,1,0): λ1= $(-1)(\theta K_l G_a + nG_b + de_a - C_a + mG_a - R_a)$, λ2= $(-1)(\theta K_l G_b + nG_a + de_b - C_b + mG_b - R_b)$, λ3=$Q_a(R_h + F_h - R_l + F_l) + Q_b(R_h + F_h - R_l + F_l) - C_h + C_l$, at this point the values of λ1, λ2 and λ3 are all uncertain and are discussed by case.

Scenario 2: If $\theta K_l G_a + nG_b + de_a - C_a > R_a - mG_a$, $\theta K_l G_b + nG_a + de_b - C_b > R_b - mG_b$, $(Q_a + Q_b)(R_h + F_h) - C_h < (Q_a + Q_b)(R_l - F_l) - C_l$, then in the case of platform negative service, the gain when both nodes share is greater than the gain when only one side shares; when both sides share, the gain of platform positive service is less than the gain of platform negative service. At this point λ1, λ2 and λ3 are all less than zero, and the point is the ESS point.

Scenario 3: If $\theta K_l G_a + nG_b + de_a - C_a > R_a - mG_a$, $\theta K_l G_b + nG_a + de_b - C_b > R_b - mG_b$, $(Q_a + Q_b)(R_h + F_h) - C_h > (Q_a + Q_b)(R_l - F_l) - C_l$, then in the case of platform negative service, the gain when both nodes share is greater than the gain when only one side shares; when both sides share, the gain from platform positive service is greater than the gain from platform negative service. At this point there is an eigenvalue greater than zero in λ1, λ2 and λ3, which is not an ESS point.

(3) E8(1,1,1): λ1=$(-1)(\theta G_a K_h + nG_b + de_a - C_a + mG_a - R_a)$, λ2=$(-1)(\theta G_b K_h + nG_a + de_b - C_b + mG_b - R_b)$, λ3=$(-1)[Q_a(R_h + F_h - R_l + F_l) + Q_b(R_h + F_h - R_l + F_l) - C_h + C_l]$, at this point the values of λ1, λ2 and λ3 are all uncertain and are discussed by case.

Scenario 4: If $\theta G_a K_h + nG_b + de_a - C_a > R_a - mG_a$, $\theta G_b K_h + nG_a + de_b - C_b > R_b - mG_b$, $(Q_a + Q_b)(R_h + F_h) - C_h > (Q_a + Q_b)(R_l - F_l) - C_l$, then, in the case of positive platform service, the gain when both nodes share is greater than the gain when only one side shares; when both sides share, the gain from positive platform service is greater than the gain from negative service, when λ_1, λ_2 and λ_3, are all less than zero, and the point is the ESS point.

Scenario 5: If $\theta G_a K_h + nG_b + de_a - C_a < R_a - mG_a$, $\theta G_b K_h + nG_a + de_b - C_b < R_b - mG_b$, $(Q_a + Q_b)(R_h + F_h) - C_h < (Q_a + Q_b)(R_l - F_l) - C_l$, then, in the case of platform positive service, the gain when both nodes share is less than the gain when only either one shares; when both share, the gain from platform positive service is less than the gain from negative service. At this point there is an eigenvalue greater than zero in λ_1, λ_2 and λ_3, which is not an ESS point.

5. MATLAB simulation analysis

To verify the validity of the evolutionary stability analysis, the article incorporates a three-way evolutionary game model, gives the model initial values and uses MATLAB for simulation. The initial values are given in the following table.

The initial values were evolved 50 times over time from different combinations of policies, respectively. As can be seen in Fig. 6, regardless of the initial probability of policy selection for the tripartite nodes, the evolutionary result tends to be (1,1,1), with the corresponding evolutionary policy being (shared, shared, active service), at which point the evolutionary result satisfies Scenario four.

Table 3 Initial values of variables

Variables	Initial value	Variables	Initial value
C_a	5	R_b	10
C_b	5	R_h	0.7
d	0.5	R_l	0.5
e_a	6	C_h	6
e_b	6	C_l	3
m	0.6	F_h	0.6
n	0.2	F_l	0.2
θ	0.4	K_h	0.8
G_a	20	K_l	0.5
G_b	20	Q_a	15
R_a	10	Q_b	15

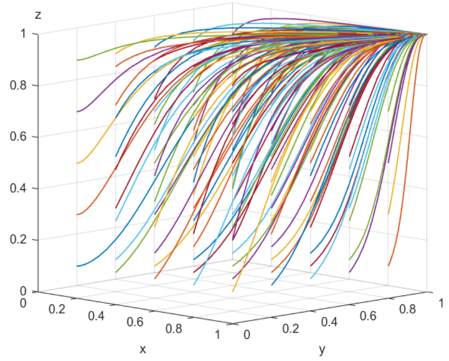

Fig. 6 Evolutionary results for scenario four

Change the initial values so that $R_a = 20$ and $R_b = 20$, and evolve the values 50 times over time from different strategy combinations respectively. As can be seen from Fig. 7, there is only one evolutionary stable strategy combination for the evolving system at this point, and the result satisfies case one, i.e. it eventually converges to (0,0,0) and the corresponding evolutionary strategy is (no share, no share, negative service).

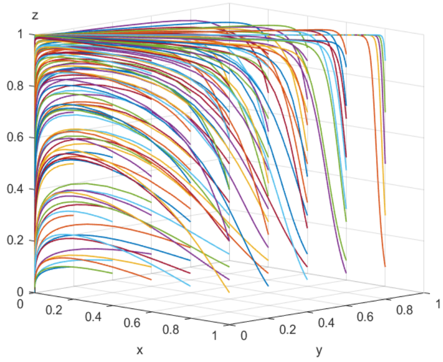

Fig. 7 Evolutionary results for scenario one

Change the value of C_h to satisfy case two. The platform is reluctant to provide positive services because the cost of positive services is too high, at which point the system evolves to a stable point (shared, shared, negative services). With blockchain technology, a reasonably set incentive and penalty for the platform to fulfil its duty to provide good service when both parties share, promoting the sharing of manufacturing capacity and avoiding negative service, as shown in Fig 8.

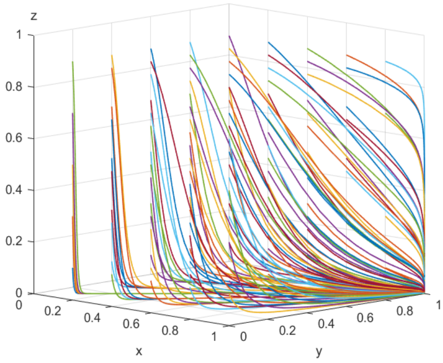

Fig. 8 Evolutionary results for scenario two

To explore the effects of changes in the initial probabilities and other parameters on the evolutionary results, P was adjusted to 0.25, 0.45 and 0.65; m was adjusted to 0.2, 0.6 and 1; n was adjusted to 0, 0.3 and 0.6; d was adjusted to 0, 0.5 and 1; F_h was adjusted to 0.2, 0.6 and 1; and F_l was adjusted to 0, 0.2, 0.4. 0.4. Observe the dynamic course of the evolutionary results over time, as shown in Figs. 9 to 14.

We can see that: as P increases, the probability that the tripartite nodes tend to share, share and actively serve increases, and the speed of evolution gradually increases. When the incentive coefficient m of blockchain technology for nodes is too low, both nodes are unwilling to share, then the platform will pay more costs for positive service than negative service, and eventually the platform will gradually choose to provide negative service; when m increases, the probability of nodes a and b sharing and platform positive service increases, and the convergence speed gradually accelerates to (1,1,1). As the penalty coefficient n increases, the evolution of both nodes choosing to share and platform positive services converge to 1 and the evolution speed gradually accelerates. Penalties under blockchain technology have a positive effect on promoting inter-node behaviour and can effectively facilitate capacity sharing between enterprises.

When the digital revenue d is too low, it will lead to the revenue when nodes share is less than the revenue when they do not share, and the nodes gradually evolve to (0,0,0). A reasonable d will promote the behaviour of sharing among enterprise nodes and active service of platform nodes, and the larger d is, the more the node evolution converges to (1,1,1) the faster the rate of convergence. The positive service of the platform can bring good reputational benefits, and as F_h gets higher, the rate of evolution of individual nodes to 1 gradually increases faster. Likewise, negative services also bring reputational losses to the platform, and the higher the F_l, the faster each node converges to 1. With blockchain technology, reasonable and effective penalties and incentives can promote positive service of platform nodes and capacity sharing of enterprise nodes.

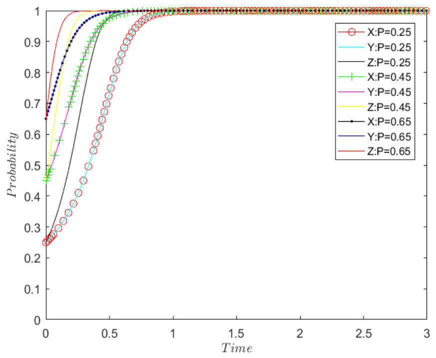

Fig. 9 Impact of P

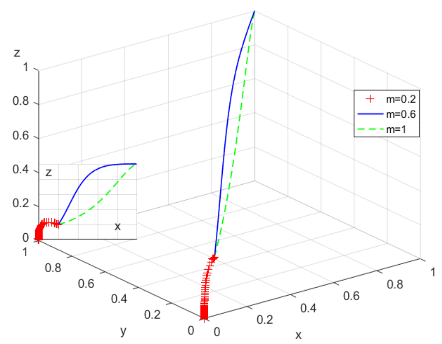

Fig. 10 Impact of m

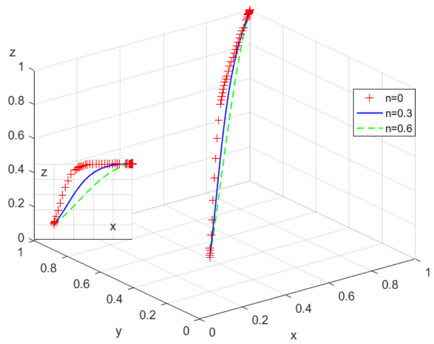

Fig. 11 Impact of n

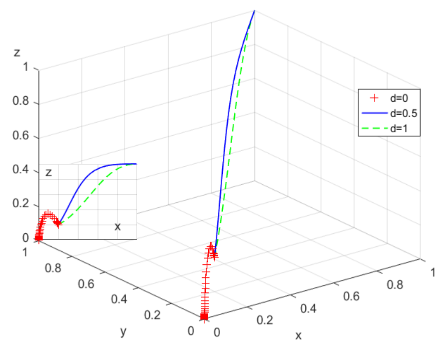

Fig. 12 Impact of d

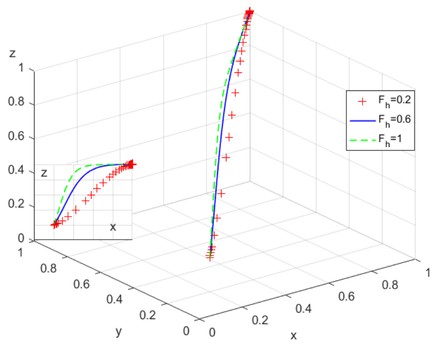

Fig. 13 Impact of F_h

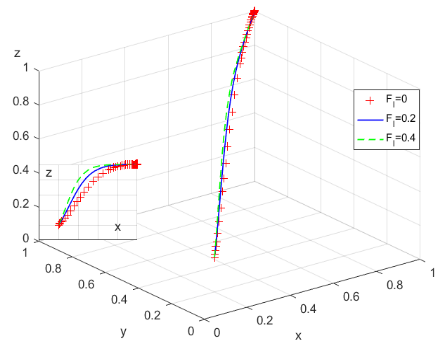

Fig. 14 Impact of F_l

6. Conclusion and management recommendations

6.1 Conclusion

From the results of the above analysis, it can be seen that:

- The game subjects will not change the evolutionary results under the initial value setting, no matter what the proportion of strategy selection is, if the relevant parameters are changed, it will have an impact on the strategy selection of the three subjects.
- Incentive and penalty coefficients are set under blockchain technology for rewarding the sharing party and punishing the non-sharing party. The incentive coefficient under blockchain technology has a positive impact on the sharing behaviour of manufacturing enterprises, and the penalty coefficient has a negative impact on the sharing behaviour of manufacturing enterprises.
- The digital benefit coefficient affects the behaviour of manufacturing enterprises, too high or too low is not conducive to the choice of manufacturing enterprises, and an appropriate digital benefit coefficient will promote the sharing behaviour of manufacturing enterprises.

- The platform under blockchain technology introduces a regulatory mechanism combined with smart contracts to constrain the behaviour of enterprises and the platform. Both positive regulation and negative regulation coefficients have a positive impact on the behaviour of the three parties.

6.2 Recommendation

Based on the above research findings, the following recommendations are made. On the one hand, the alliance nodes under blockchain technology can appropriately optimize the incentive mode and penalty mode, and find suitable allocation coefficients to maximize the incentive for the capacity-sharing behaviour of both supply and demand sides and promote the cooperation between them; at the same time, the third-party platform should actively supervise and strengthen its supervisory capacity to avoid the emergence of malicious pigeonholing behaviour, improve the effective cooperation between supply and demand sides and promote the long-term development of the manufacturing industry. In addition, both supply and demand sides should maintain good integrity to help create a good market environment, thus promoting the benign development of the manufacturing industry.

6.3 Shortcomings

The article uses an evolutionary game approach to investigate the capacity sharing behaviour of manufacturing firms and uses numerical simulations in MATLAB to analyse the effect of changes in different parameters on the evolutionary outcome. However, the article does not consider the effects of other aspects such as product quality, delivery time, human emotion, social development and environment on the game behaviour of capacity sharing, which can be further explored by introducing prospect theory in the future, and I am currently conducting related research.

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References

[1] Dai, H.-N., Zheng, Z., Zhang, Y. (2019). Blockchain for Internet of things: A survey, *IEEE Internet of Things Journal*, Vol. 6, No. 5, 8076-8094, doi: 10.1109/JIOT.2019.2920987.

[2] Hariri, R.H., Fredericks, E.M., Bowers, K.M. (2019). Uncertainty in big data analytics: Survey, opportunities, and challenges, *Journal of Big Data*, Vol. 6, No. 1, Article No. 44, doi: 10.1186/s40537-019-0206-3.

[3] Zhang, C., Lu, Y. (2021). Study on artificial intelligence: The state of the art and future prospects, *Journal of Industrial Information Integration*, Vol. 23, Article No. 100224, doi: 10.1016/j.jii.2021.100224.

[4] Abhishek, V., Guajardo, J.A., Zhang, Z. (2021). Business models in the sharing economy: Manufacturing durable goods in the presence of peer-to-peer rental markets, *Information Systems Research*, Vol. 32, No. 4, 1450-1469, doi: 10.1287/isre.2021.1034.

[5] Ojstersek, R., Javernik, A., Buchmeister, B. (2021). The impact of the collaborative workplace on the production system capacity: Simulation modelling vs. real-world application approach, *Advances in Production Engineering & Management,* Vol. 16, No. 4, 431-442, doi: 10.14743/apem2021.4.411.

[6] Guo, L., Wu, X. (2018). Capacity sharing between competitors, *Management Science*, Vol. 64, No. 8, 3554-3573, doi: 10.1287/mnsc.2017.2796.

[7] Chen, J., Wang, X., Chu, Z. (2020). Capacity sharing, product differentiation and welfare, *Economic Research-Ekonomska Istraživanja*, Vol. 33, No. 1, 107-123, doi: 10.1080/1331677X.2019.1710234.

[8] Fang, D., Wang, J. (2020). Horizontal capacity sharing between asymmetric competitors, *Omega*, Vol. 97, Article No. 102109, doi: 10.1016/j.omega.2019.102109.

[9] Nofer, M., Gomber, P., Hinz, O., Schiereck, D. (2017). Blockchain, *Business & Information Systems Engineering*, Vol. 59, No. 3, 183-187, doi: 10.1007/s12599-017-0467-3.

[10] Berdik, D., Otoum, S., Schmidt, N., Porter, D., Jararweh, Y. (2021). A survey on blockchain for information systems management and security, *Information Processing & Management*, Vol. 58, No. 1, Article No. 102397, doi: 10.1016/j.ipm.2020.102397.

[11] Karamchandani, A., Srivastava, S.K., Kumar, S., Srivastava, A. (2021). Analysing perceived role of blockchain technology in SCM context for the manufacturing industry, *International Journal of Production Research*, Vol. 59, No. 11, 3398-3429, doi: 10.1080/00207543.2021.1883761.

[12] Catalini, C., Gans, J.S. (2020). Some simple economics of the blockchain, *Communications of the ACM*, Vol. 63, No. 7, 80-90, doi: 10.1145/3359552.

[13] Wang, X.L. (2021). Game-based hybrid particle swarm optimization of job-shop production control, *International Journal of Simulation Modelling*, Vol. 20, No. 2, 398-409, doi: 10.2507/IJSIMM20-2-CO9.

[14] Xiao, M.; Tian, Z.Y. (2022). Evolutionary game analysis of company collaborative strategy in cloud manufacturing platform environment, *Advances in Production Engineering & Management*, Vol. 17, No. 3, 295-310, doi: 10.14743/apem2022.3.437.

[15] Xiong, H., Dalhaus, T., Wang, P., Huang, J. (2020). Blockchain technology for agriculture: Applications and rationale, *Frontiers in Blockchain,* Vol. 3, No. 7, doi: 10.3389/fbloc.2020.00007.

[16] Yang, S.Y, Tan, C. (2022). Blockchain-based collaborative management of job shop supply chain, *International Journal of Simulation Modelling,* Vol. 21, No. 2, 364-374, doi: 10.2507/IJSIMM21-2-CO10.

[17] Chang, V., Baudier, P., Zhang, H., Xu, Q., Zhang, J., Arami, M. (2020). How blockchain can impact financial services–The overview, challenges and recommendations from expert interviewees, *Technological Forecasting and Social Change*, Vol. 158, Article No. 120166, doi: 10.1016/j.techfore.2020.120166.

[18] Yan, K., Cui, L., Zhang, H., Liu, S., Zuo, M. (2022). Supply chain information coordination based on blockchain technology: A comparative study with the traditional approach, *Advances in Production Engineering & Management*, Vol. 17, No. 1, 5-15, doi: 10.14743/apem2022.1.417.

[19] Abeyratne, S.A., Monfared, R.P. (2016). Blockchain ready manufacturing supply chain using distributed ledger, *International Journal of Research in Engineering and Technology*, Vol. 5, No. 9, 1-10, doi: 10.15623/ijret.2016.0509001.

[20] Leng, J., Ruan, G., Jiang, P., Xu, K., Liu, Q., Zhou, X., Liu, C. (2020). Blockchain-empowered sustainable manufacturing and product lifecycle management in industry 4.0: A survey, *Renewable and Sustainable Energy Reviews*, Vol. 132, Article No. 110112, doi: 10.1016/j.rser.2020.110112.

[21] Li, J., Maiti, A., Springer, M., Gray, T. (2020). Blockchain for supply chain quality management: Challenges and opportunities in context of open manufacturing and industrial internet of things, *International Journal of Computer Integrated Manufacturing*, Vol. 33, No. 12, 1321-1355, doi: 10.1080/0951192X.2020.1815853.

[22] Tian, C. (2020). Study of innovation manufacturing capacity sharing mode based on blockchain, *Science and Technology Management Research*, Vol. 40, No. 11, 9-14, doi:10.3969/j.issn.1000-7695.2020.11.002.

[23] Wang, T., Zhang, H. (2022). Evolutionary game study on manufacturing capacity sharing based on block chain, In: *Proceedings of 2022 3rd International Conference on Electronics, Communications and Information Technology (CECIT),* Sanya, China, 373-378, doi: 10.1109/CECIT58139.2022.00071.

[24] Hao, J.-Q., Zhao, D.-Z. (2021). Tripartite-players evolutionary game analysis of the manufacturing capacity sharing in the environment of sharing economy, *Operations Research and Management Science*, Vol. 30, No. 2, 1-7.

[25] Xin, Y.-L. (2020). Evolutionary game analysis of manufacturing enterprise capacity sharing strategy from the perspective of competition and cooperation, *Technology and Innovation Management,* No. 4, 375-379, doi: 10.14090/j.cnki.jscx.2020.0409.

[26] Zhu, L.-L., Rong, J.-M., Zhang, S.-Y. (2021). Three-party evolutionary game and simulation analysis of drug quality supervision under the government reward and punishment mechanism, *Chinese Journal of Management Science*, Vol. 2021, No. 11, 55-67, doi: 10.16381/j.cnki.issn1003-207x.2019.0481.