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Research on the Cooperation Strategy of Rail-road Transportation Enterprises under the Participation of Blockchain Technology

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Abstract: With the wide application of blockchain technology in the logistics supply chain, the conflict of interest between the road-rail transportation enterprises has become a vital research hotspot. To study the evolution law of the cooperation strategy of rail-road transportation enterprises under different reward and punishment mechanisms. Based on the evolutionary game theory, this paper constructs the three groups' evolutionary game model of blockchain technology platform, road transportation enterprises, and rail transportation enterprises to analyze the stability conditions of each node enterprise and test the effectiveness of the research results. This paper puts forward countermeasures and suggestions for relevant stakeholders.

1. Introduction

In recent years, the cooperation and competition between global economies has gradually escalated, and the synergy and development between the main enterprises of public-rail intermodal transportation has also received more and more attention from all walks of life. At this stage, information asymmetry and low trust among logistics enterprises have led to low efficiency of intermodal transportation, high cost of cooperation between public and railroad transportation enterprises, deepening conflict of interest, and more and more difficulties in demand forecasting. Therefore, there is an urgent need for new technologies and new ideas to solve these problems.[1] As an independent third-party organization, the blockchain technology platform party does not have any interest entanglement with the enterprises related to public-rail intermodal transportation, and its smart contract characteristics are more fair and credible. Currently, there are more studies on blockchain technology in finance, healthcare, and logistics supply chain, but there is less literature on blockchain technology platform institutions regulating the partnership between public and rail transportation companies. Therefore, based on the research related to public-rail transportation, it is significant to explore whether to introduce the supervision of blockchain technology platform institutions and how to develop the supervision mechanism of public-rail transportation enterprise partnership.

At present, there are some research results in the academic community for blockchain technology to improve the operation of logistics supply chain enterprises. Jihye, S [3]used blockchain technology to facilitate cooperation between nodes in the chain by building a decentralized model of a new supply chain collaboration process. De Giovanni, P.[4] designed a supply chain game model consisting of suppliers and retailers. By comparing the traditional online platform with the blockchain technology management platform, it was found that working on the blockchain platform can share all the federated chain public information thus eliminating the risk in the supply chain and saving the transaction cost. Huiqin, Y[5] use the characteristics of data transparency and decentralization of blockchain technology to solve the untimely information interaction in the traditional supply chain, construct a blockchain-centered supply alliance information platform, and verify the superiority of the platform with the automotive supply chain as an example. In terms of enterprise cooperation, Dutta, Pankaj et al[6] proposed a new model of three-party game in public-rail intermodal transportation system under the government's domination, which provides a new idea for the cooperative development of public-rail transportation enterprises. Ruihuan, L[7] improves the operational efficiency of supply chain enterprises by introducing blockchain technology, which makes the cooperation among the node enterprises of the supply chain more predictable, and in turn, improves the management mode of business processes. At present, most of the researches on the application of blockchain technology in the field of logistics supply chain focus on information sharing and operational efficiency, and there are fewer researches on the stability of cooperation among logistics enterprises. Based on this, this paper tries to explore the introduction of blockchain technology to formulate a reasonable supervision mechanism of public-rail intermodal transport on the basis of the research related to public-rail intermodal transport, so as to standardize the cooperation behavior of public-rail transport enterprises and promote the continuous healthy and stable development of public-rail intermodal transport.

2. Model building

Evolutionary game theory believes that the subject of decision-making is bounded and rational and cannot respond quickly to changes in economic phenomena. It is always necessary to make optimal decisions through continuous learning and imitation to achieve the best results. With the participation of blockchain technology platforms, the cooperation of rail-road transportation enterprises has the same characteristics. Due to the problems of information asymmetry and mutual distrust in the recent collaboration of rail-road transportation, and the unclear benefits generated by the cooperation between highway transport enterprises and railway transport enterprises, the blockchain technology platform organization is also unclear about whether it can obtain excess benefits when introduced into rail-road transportation enterprises. The three parties can only gradually observe, learn, and imitate the decision-making behavior of other decision-making subjects in the same industry in their participation and cooperation to continuously make dynamic adjustments and achieve the purpose of improving their respective benefits. Therefore, under the guidance of the evolutionary game method, this article researches the collective interests of rail-road transportation enterprises with the participation of blockchain technology platform institutions.

2.1. Basic assumptions

Participants in the evolutionary game include road transportation companies (H), railway transportation companies (R), and blockchain technology platforms. The three central bodies represent three groups. The blockchain technology platform actively introduces road-rail transportation companies to promote the road-rail intermodal transportation policy through supervision, setting up reward mechanisms and penalties, or not introducing it. Therefore, the behavioral strategy space of the blockchain technology platform is {introduce, no introduce}； In the cooperation between rail-road transportation companies, both parties can freely choose whether to cooperate or not according to the business status of the companies themselves. Therefore, the behavior strategy space of road transportation companies and railway transportation companies is {cooperation, no cooperation}.

Considering that the strategy in game theory is based on the problem of benefit distribution, the following nine assumptions mainly discuss the relationship between game subjects from the factors such as the excess return obtained by cooperation, the early investment cost, the risk cost, and the level of trust between both sides.

Hypothesis 1: Assume that the probability of a railway transportation company choosing "cooperation" is x; the possibility of a road transportation company choosing "cooperation" is y; the possibility of a blockchain technology platform choosing "introduction" is z. where $0 \leq x, y, z \leq 1$.

Hypothesis 2: Railway transportation companies and road transportation companies have their business scopes. When the two parties adopt a non-cooperative strategy, the profits of independent operation are π_1 and π_2.where π_1, π_2>0. The blockchain technology platform punishes rail-road transportation enterprises P1 and P2, respectively. As a result, the rail-road intermodal transportation is broken, and the blockchain platform shall bear the losses caused to society w.

Hypothesis 3: Assume that the rail-road transportation companies can obtain excess income π when they cooperate. At this time, the distribution ratio of the extra income is a,(1-a), where $\pi > 0, 0 < a < 1$. The blockchain technology platform rewards them E1 and E2, respectively.

Hypothesis 4: The cooperation between rail-road transportation enterprises needs to produce negotiation, logistics, and related management costs. Suppose one party is more willing to cooperate than the other. In that case, the party with a greater willingness to cooperate will incur related charges for the two parties to cooperate. Therefore, regardless of whether the two parties form a partnership, in the end, there is a cooperation cost C, and the cost-sharing ratio of the road and railway transportation companies when they cooperate is $b, (1-b), C > 0, 0 < b < 1$.

Hypothesis 5: Because the cooperation of highway and railway transportation enterprises will promote the two parties to learn each other's advanced technology and logistics management experience, the other party's strength will increase, and there will be a specific risk of technology spillover. Therefore, there will be risks after the two parties cooperate. Where r>0.

Hypothesis 6: The cooperation between the two parties is related to the degree of trust. If the rai-road transportation companies have a high degree of trust in each other, the probability of reaching cooperation will increase. Therefore, suppose the trust coefficient of railway transportation companies to road transportation companies is $t_{r,h}$, and the trust coefficient of road transportation companies to railway transportation companies is $t_{h,r}$, where $0 < t_{r,h}, t_{h,r} < 1$.

Hypothesis 7: The management cost of the blockchain platform for the rail-road transportation companies is m.

Hypothesis 8: If one of the road transport companies or the railway transport companies chooses to "no cooperate," the blockchain technology platform organization bears the negative cost n caused by the non-cooperation.

Hypothesis 9: When the two parties form a partnership and work together to reduce transportation costs and improve efficiency, the government rewards the blockchain platform organization as Q.

2.2. Model building

In the three-group evolutionary game model, the critical consideration is the evolutionary influence of the intelligent contract mechanism of blockchain technology on the cooperation strategy of road-rail transportation companies. Based on the above assumptions and evolutionary game ideas, build a payment matrix, as shown in Table 1. The final sentence of a caption must end with a period.

Table 1: Tripartite game payment matrix.

Behavior strategy		Blockchain technology platform			
		Introduce/z		No Introduce/1-z	
		H			
		Cooperation y	No cooperation 1-y	Cooper-ation y	No cooperation 1-y
R	Cooper-ation x	$L_{11}+E_1$	$L_{12}+E_1$	L_{11}	L_{12}
		$L_{21}+E_2$	$L_{22}-P_2$	L_{21}	L_{22}
		$Q-E_1-E_2-M$	P_2-E_1-M-N	0	0
	No coopera-tion 1-x	$L_{13}-P_1$	$L_{14}-P_1$	L_{13}	L_{14}
		$L_{23}+E_2$	$L_{24}-P_2$	L_{23}	L_{24}
		P_1-E_2-M-N	P_1+P_2-M-W	0	0

$$L_{11}=\pi_1+a\pi-(1-t_{r,h})ra\pi-bC\,,L_{12}=\pi_1-bC\,,L_{13}=\pi_1,L_{14}=\pi_1,$$
$$L_{21}=\pi_2+(1-a)\pi-(1-t_{h,r})r(1-a)\pi-(1-b)C\,,L_{22}=\pi_2\,,L_{23}=\pi_2-(1-b)C\,,L_{24}=\pi_2\,.$$

The size relationships among L_{11}, L_{12}, L_{13}, L_{14}, L_{21}, L_{22}, L_{23}, L_{24} are as follows: $L_{11}>L_{13}=L_{14}>L_{12}$, $L_{21}>L_{22}=L_{24}>L_{23}$.

In the above game matrix, the expected return when the railway transportation enterprise R adopts cooperation is:

$$F_{11}=yz(L_{11}+E_1)+(1-y)z(L_{12}+E_1)+y(1-z)L_{11}+(1-y)(1-z)L_{12} \tag{1}$$

When railway transportation company R chooses the "non-cooperation" strategy, the benefits that can be obtained are:

$$F_{12}=yz(L_{13}-P_1)+(1-y)z(L_{14}-P_1)+y(1-z)L_{13}+(1-y)(1-z)L_{14} \tag{2}$$

Average return:

$$\overline{F_1}=xF_{11}+(1-x)F_{12} \tag{3}$$

From this, we can draw the dynamic equation of replication for the choice of cooperation between railway transport companies:

$$\begin{aligned}F(x)&=x(F_{11}-\overline{F_1})=x(1-x)(F_{11}-F_{12})\\&=x(1-x)[y(L_{11}-L_{13}-L_{12}+L_{14})+z(E_1+P_1)+(L_{12}-L_{14})]\end{aligned} \tag{4}$$

In the same way, the dynamic equation for replication of road transport companies can be obtained:

$$\begin{aligned}F(y)&=y(F_{21}-\overline{F_2})=y(1-y)(F_{21}-F_{22})\\&=y(1-y)[x(L_{21}-L_{22}-L_{23}+L_{24})+z(E_2+P_2)+(L_{23}-L_{24})]\end{aligned} \tag{5}$$

The dynamic replication equation of the blockchain technology platform:

$$\begin{aligned}F(z)&=z(F_{31}-\overline{F_3})=z(1-z)(F_{31}-F_{32})\\&=z(1-z)[xy(Q+2N-W)+x(W-E_1-P_1-N)+y(W-E_2-P_2-N)+(P_1+P_2-M-W)]\end{aligned} \tag{6}$$

3. Model analysis

3.1. Analysis of the equilibrium point of the evolution process

Friedman proposed that the local equilibrium point is not necessarily the system's evolutionary stability strategy (ESS). The stability of the evolutionary equilibrium point can be obtained from the regional stability analysis of the Jacobian matrix of the system. If $F(x)=0$ and $F'(x)<0$, x is evolutionary stability strategy (ESS) of the system. Let $F(x)=F(y)=F(z)=0$ the equilibrium point of the three-dimensional dynamic system can be obtained:

$$L1(0,0,0),L2(0,0,1),L3(0,1,0),L4(1,0,0),L5(0,1,1),L6(1,0,1),L7(1,1,0),L8(1,1,1),$$

$$L9(0,\frac{P_1+P_2-M-W}{E_2+P_2+N-W},\frac{L_{24}-L_{23}}{E_2+P_2}),L10(1,\frac{E_1-P_2+M+N}{Q+N-E_2-P_2},\frac{L_{22}-L_{21}}{E_2+P_2}),L11(\frac{P_1+P_2-M-W}{E_1+P_1+N-W},0,\frac{L_{14}-L_{12}}{E_1+P_1}),L12(\frac{E_2+P_1+M+N}{Q+N-E_1-P_1},1,\frac{L_{13}-L_{11}}{E_1+P_1}),L13(\frac{L_{24}-L_{23}}{L_{21}-L_{22}-L_{23}+L_{24}},\frac{L_{14}-L_{12}}{L_{11}-L_{13}-L_{12}+L_{14}},0),$$

$$L14(\frac{L_{24}-L_{23}-E_2-P_2}{L_{21}-L_{22}-L_{23}+L_{24}},\frac{L_{14}-L_{12}-E_1-P_1}{L_{11}-L_{13}-L_{12}+L_{14}},1),L15(x_1,y_1,z_1),L16(x_2,y_2,z_2)$$

3.2. Stability analysis

Table 2: Jacobian matrix eigenvalues.

balance point	Eigenvalues		
	β_1	β_2	β_3
$L_1(0,0,0)$	$L_{12}-L_{14}$	$L_{23}-L_{24}$	P_1+P_2-M-W
$L_2(0,0,1)$	$E_1+P_1+L_{12}-L_{14}$	$E_2+P_2+L_{23}-L_{24}$	$-(P_1+P_2-M-W)$
$L_3(0,1,0)$	$L_{11}-L_{13}$	$-(L_{23}-L_{24})$	$P_1-M-N-E_2$
$L_4(1,0,0)$	$-(L_{12}-L_{14})$	$L_{21}-L_{22}$	$P_2-M-N-E_1$
$L_5(0,1,1)$	$L_{11}-L_{13}+E_1+P_1$	$-(E_2+P_2+L_{23}-L_{24})$	$-(P_1-M-N-E_2)$
$L_6(1,0,1)$	$-(E_1+P_1+L_{12}-L_{14})$	$L_{21}-L_{22}+E_2+P_2$	$-(P_2-M-N-E_1)$
$L_7(1,1,0)$	$-(L_{11}-L_{13})$	$-(L_{21}-L_{22})$	$Q-E_1-E_2-M$
$L_8(1,1,1)$	$-(L_{11}-L_{13}+E_1+P_1)$	$-(L_{21}-L_{22}+E_2+P_2)$	$-(Q-E_1-E_2-M)$

According to the Lyapunov stability theory, the symbol of the eigenvalues of the Jacobian matrix can deduce the stability of the equilibrium point of the system. If the eigenvalue corresponding to the equilibrium point is less than zero, the point is stable; if it is greater than zero, the point is unstable; if it is greater than zero and less than zero, it is a saddle point.

As can be seen from the above table 2, point $L_1(0,0,0)$ has three eigenvalues: $L_{12}-L_{14},L_{23}-L_{24},P_1-P_2-M-W$,where$L_{12}-L_{14}<0,\ L_{23}-L_{24}<0$, Among the three eigenvalues of point $L_8(1,1,1)$, $-(L_{11}-L_{13}+E_1+P_1)<0,-(L_{21}-L_{22}+E_2+P_2)<0$, By judging the signs of$P_1+P_2-M-W$and$-(Q-E_1-E_2-M)$, we can know whether the points L_1 (0, 0, 0) and L_8 (1, 1, 1) are stable points. Considering the long-term development and stability of road-rail transportation enterprises, $L_8(1,1,1)$ is the stable point, and $L_1(0,0,0)$ is the unstable point, the final desired result. At this time:

$$P_1+P_2-M-W>0,\ P_1+P_2>M+W$$

$$-(Q-E_1-E_2-M)<0,\ Q>E_1+E_2+M$$

Therefore:

(1) Enterprises R and H choose the "non-cooperation," which leads to the breakdown of cooperation and will pay liquidated damages. When the blockchain technology platform institution decides to increase the punishment for this behavior, that is, increase P_1 and P_2, which will increase both parties' stability of cooperation. To avoid the occurrence of this phenomenon, the two parties will tend to evolve toward cooperation. One of the benefits of blockchain technology platform institutions is collecting liquidated damages, which will strengthen their supervision of the collaboration of road-rail transportation companies, and the three-party strategy will eventually tend to (Cooperation, cooperation, introduction).

(2) In addition, increasing government rewards for blockchain technology platform institutions for regulatory activities, and reducing the cost of institutions borne by road-rail transportation companies due to the breakdown of cooperation, will increase the enthusiasm of blockchain technology platform institutions, which is conducive to the stable development of road-rail intermodal transport.

(3) Increasing the blockchain technology platform institutions to punish the road and railway transportation companies for choosing non-cooperative strategies will make the road and railway transportation companies tend to select cooperation strategies. If the blockchain technology platform organization rewards companies that actively cooperate, that is, increase E_1 and E_2, the initial stage of the road and rail transportation companies tend to cooperate faster and quickly stabilize their performance. With the increase in the reward value of the blockchain technology platform organization, when E increases $Q<E_1+E_2+M$, the cost of its payment will also increase significantly, reducing the platform organization's initiative to implement intelligent contract supervision.

(4) It increased the government's reward Q for blockchain technology platform institutions for regulatory activities. It reduced the cost M and loss W borne by the institutions due to the breakdown of the cooperation between road and railway transportation companies. This measure will promote intelligent contracts for blockchain technology platform institutions to monitor and control enterprises actively. It will be conducive to road and railway transportation companies to obtain excess returns. Still, the excess returns of the cooperation between the two parties result from various market economy influences, which will fluctuate within a specific range in the long run. This shows that the current strategic cooperation can only achieve the effect of short-term resource complementarity. With the deepening of the contradiction between the competition and collaboration of logistics and transportation enterprises, future collaboration between the three parties should also find a new balance.

4. Conclusions

This paper analyzes the evolutionary path of the cooperative relationship among the three groups by constructing the evolutionary game model among the road transport enterprises, railroad transport enterprises and blockchain technology platform, and carries out simulation and result analysis. The result study shows that:

(1) For public railway transportation enterprises, in addition to signing relevant treaties to constrain their cooperative behavior when they join the intermodal transportation, they should also consider introducing blockchain technology, which can fairly and objectively and intelligently safeguard the interests of enterprise cooperation. This can not only avoid the betrayal of cooperation such as opportunism and withdrawal from intermodal transportation in the process of cooperation, but also save the resources of public railway transportation enterprises.

(2) The stability of the cooperative relationship between public-rail transportation enterprises and the blockchain technology platform is affected by a number of factors, such as the initial willingness

to cooperate between public-rail transportation enterprises, excess returns, cooperation costs, sharing ratio, risk level, trust relationship, and the reward and punishment mechanism of the blockchain technology platform.

(3) Increasing the government's incentives for the blockchain technology platform to carry out supervision and reducing the costs borne by rupture institutions due to the cooperation of public-railway transportation enterprises will promote the blockchain technology platform to actively adopt smart contracts to supervise and control the enterprises, which is conducive to the public-railway transportation enterprises to obtain excess returns, but the excess returns of the two parties' cooperation is the result of the influence of many aspects of the market economy, and will fluctuate within a certain range in the long run. This shows that the current strategic cooperation can only achieve the effect of short-term resource complementarity, and with the deepening of the contradiction of the competitive relationship between logistics and transportation enterprises in China's market economy, the future cooperation between the three parties should also look for a new balance point.

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