Research on tripartite evolutionary game and simulation of cold chain food traceability system

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Abstract. Cold chain food safety problems emerge one after another, which is an important factor affecting the safe and stable development of society, how to reduce the probability of food safety and quickly solve safety incidents has become the key to the problem. Taking cold-chain food as an example, establish a cold-chain food traceability system to promote the transparency of cold-chain food information, reduce the cost of enterprise compensation, and meet consumers' demands for the quality and safety of cold-chain food. A tripartite evolutionary game model with government departments, producers and consumers as the main body was constructed to obtain the stability conditions of the game system, and the system dynamics simulation model was constructed through Vensim software to analyze and verify the stability policy conditions of each subject. The results show that government departments should improve the relevant industry policies and establish appropriate reward and punishment mechanisms for cold chain food traceability, manufacturers should actively respond to the call of government departments to vigorously develop and operate cold chain food traceability systems, and consumers should actively participate in the supervision of cold chain food traceability systems.

Keywords: Cold chain logistics, Food safety, Tripartite evolutionary game, System dynamics

1 Introduction

In recent years, China's economy has developed rapidly, people's living standards have improved rapidly, and the quality and safety of cold chain food is the focus of national attention. The issue of cold chain food safety poses a great threat to ordinary people, and if left unchecked, it will undermine the sustainable development of people's lives. Jhao-Yi Wu et al. reduce the food quality and safety risks of cold chain systems in advance by using failure modes to assess the possible risks of cold chain foods and treating them with other case models [1]. In order to solve the problem of cold chain food safety, Liu Fangfang and other scholars have established a food safety credit evaluation system, and reduced the problem of cold chain food safety by establishing

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professional evaluation institutions and evaluation indicators [2]. In the context of increasingly stringent food quality safety and cold chain traceability, the construction of a cold chain food traceability system has become a top priority [3,8].

Commodity traceability refers to the integration of information flow in the whole process of goods from production to producers [4]. Scholar Vichaidis W proposed that the use of IoT and blockchain technology in the cold chain logistics industry can increase the integrity of cold chain food data and the traceability of commodity information [5].In the research on the traceability system, Islam S. and other scholars believe that the current food traceability system is not perfect, and the traceability information system may suffer from problems such as information loss and inaccurate recorded information [6]. On this basis, Zhiyuan Li et al. have integrated blockchain technology with edge computing and other technologies to construct a credit mechanism demonstration and verification system to verify how blockchain technology prevents data tampering [7]. Taking Ningxia cabbage as an example, Zhuangzhuang L verified that blockchain technology has a good traceability effect on cold-chain commodities and can increase the safety of cold-chain foods [8].Chen scholars believe that in the multilayered supply chain system, manufacturers play a key role as the initial builder of the traceability system, which can allow manufacturers to obtain greater benefits and reduce the risk of claims by manufacturers [9]. Cao Yu et al. found that if the government strengthens supervision and punishment measures, it will be conducive to the integrity development of the traceability system [10]. Through the research of scholars on the traceability system of other commodities, it is found that the traceability system of cold chain commodities can introduce blockchain technology and Internet of Things technology to ensure the authenticity and reliability of traceability information, and the construction of the traceability system requires the participation and coordination of multiple parties in the supply chain[11].

Based on the existing research, the cold chain food is combined with the traceability system to improve the food safety guarantee coefficient of the cold chain. This paper analyzes the behavioral characteristics of different participants in the cold chain food traceability system, constructs a tripartite evolutionary game model with government departments, manufacturers and consumers as the main body, and analyzes the changes in the strategy choice among each subject, so as to provide a theoretical basis for the construction of the cold chain food traceability system.

2 Model building and analysis

2.1 Problem description and basic assumptions

In the whole production cycle of cold chain food, food traceability is the joint participation of the main body of the supply chain. This paper mainly constructs a tripartite evolutionary game model with government departments, manufacturers, and consumers as the main body. Combined with the tripartite evolutionary game model and the traceability characteristics of cold chain food, this paper makes the following assumptions:

(1) Game Subject: The three parties in this study are: government departments, manufacturers, and consumers.

(2) The game subjects in this study pursue the goal of profit maximization in the market environment, and they are all bounded rationality, and the decision-making strategy is corrected through continuous trial and error to find the most effective game strategy.

(3) According to the willingness of the participants of the tripartite game, the policy set of government departments is (supervision, non-supervision), the strategy set of producers is (participation, non-participation), and the strategy set of consumers is (buying, non-buying).

2.2 Model parameter setting and construction

The probability of government departments choosing to "supervise" the traceability of cold-chain food is "x", and vice versa is "1-x", the probability of producers "participating" in the traceability of cold-chain food is "y", and vice versa is "1-y", and the probability of consumers "buying" cold-chain traceable food is "z", and vice versa is "1-z". The total cost of government expenditures is "P_g"; Producers participate in the cost of cold chain food traceability "P_m";The cost of consumers purchasing cold-chain traceable food "P_c"; Government departments regulate revenues "E_g"; Manufacturers participate in the traceability of cold chain food "E_m"; Consumers buy cold chain traceability food safety benefits "E_c"; Financial incentives from government departments "A_1"; Consumer feedback on the credibility incentives of government departments "A_2"; The probability of safety problems in cold chain foods "a"; Government departments supervise the traceability of cold chain food, and the cost of accountability for food problems "F_{g1}"; The cost of accountability when government departments do not regulate "F_{g2}"; Manufacturers participate in the cost of compensation for food problems in the cold chain food traceability "F_{m1}"; The cost of compensation when the producer does not participate "F_{m2}"; The cost of complaints about food problems caused by consumers buying cold chain traceable food "F_{c1}"; The cost of complaints about food problems when consumers purchase ordinary cold chain goods "F_{c2}".

Based on the above model assumptions and parameter settings, an evolutionary game payment matrix composed of government departments, manufacturers, and consumers is established, as shown in Table 1.

Table 1. Game pay-off matrix

Game player					Government Department	
					Supervise (x)	non-supervisio$(1-x)$
producer	Partici-pation	Con-	(z)	Buying	$E_g + A_2 - P_g - A_1 - a \cdot F$	$A_2 - (1-a) \cdot F_{g2}$
					$E_m + A_1 - P_m - a \cdot F_{m1}$	$E_m - P_m - a \cdot F_{m1}$

			$E_c - P_c - a \cdot F_{c1}$	$E_c - P_c - a \cdot F_{c1}$
		Non-buying $(1-z)$	$E_g - P_g - A_1 - a \cdot F_{g1}$	$-(1-a) \cdot F_{g2}$
			$E_m + A_1 - P_m - a \cdot F_{m1}$	$E_m - P_m - a \cdot F_{m1}$
			$-(1-a) \cdot F_{c2}$	$-(1-a) \cdot F_{c2}$
Non-participation $(1-y)$	Consumer	Buying (z)	$E_g + A_2 - P_g - a \cdot F_{g1}$	$A_2 - (1-a) \cdot F_{g2}$
			$-(1-a) \cdot F_{m2}$	$-(1-a) \cdot F_{m2}$
			$E_c - P_c - a \cdot F_{c1}$	$E_c - P_c - a \cdot F_{c1}$
		Non-buying $(1-z)$	$E_g - P_g - a \cdot F_{g1}$	$-(1-a) \cdot F_{g2}$
			$-(1-a) \cdot F_{m2}$	$-(1-a) \cdot F_{m2}$
			$-(1-a) \cdot F_{c2}$	$-(1-a) \cdot F_{c2}$

2.3 Model evolution analysis

According to Table 1, the replication dynamic equations of government departments, producers, and consumers can be obtained:

$$F(x) = x \cdot (1-x) \cdot \begin{bmatrix} yz(E_g + A_2 - P_g - a \cdot F_{g1}) - yA_1 \\ + (1-a)F_{g2} + E_g - P_g - a \cdot F_{g1} \end{bmatrix} \tag{1}$$

$$F(y) = y \cdot (1-y) \cdot [xA_1 + E_m - P_m - a \cdot F_{m1} + (1-a) \cdot F_{m2}] \tag{2}$$

$$F(z) = z \cdot (1-z) \cdot [E_c - P_c - a \cdot F_{c1} + (1-a) \cdot F_{c2}] \tag{3}$$

According to the strategy selection of government departments, the evolution path is analyzed, and the government department strategy is in a stable state when "$F(x) = 0$" and "$\frac{\delta F(x)}{\delta x} < 0$". That is, when "$y^* = \frac{P_g + a \cdot F_{g1} - E_g - (1-a) \cdot F_{g2}}{z(E_g + A_2 - P_g - a \cdot F_{g1}) - A_1}$", at this time, "$F(x) \equiv 0$", that is, "x" takes any value, the government departments are in a state of evolutionary stability. When "$1 > y > y^* > 0$", "$x = 1$" meets the equation steady state condition, the government department will choose the "supervision" strategy, and when "$0 < y < y^* < 1$", "$x = 0$" meets the equation steady state condition, the government department will choose the "non-supervision" strategy.

The evolution path analysis is carried out according to the manufacturer's strategy choice, and the manufacturer's strategy is in a stable state when "$F(y) = 0$" and "$\frac{\delta F(y)}{\delta y} < 0$". When "$x^* = \frac{P_m + a \cdot F_{m1} - (1-a) \cdot F_{m2} - E_m}{A_1}$", at this time, "$F(y) \equiv 0$", that is, "y" takes any value, the producer is in an evolutionary stable state.

When “$0 < x < x^* < 1$”, “$y = 0$” meets the equation steady-state condition, the producer chooses the “non-participation” strategy, and when “$1 > x > x^* > 0$”, “$y = 1$” meets the equation steady-state condition, the producer chooses the “participation” strategy.

The evolution path is analyzed according to the consumer's strategy choice, and the consumer strategy is in a stable state when “$F(z) = 0$” and “$\frac{\delta F(z)}{\delta z} < 0$”. When “$E_c + (1-a) \cdot F_{c2} = P_c + a \cdot F_{c1}$”, at this time, “$F(z) \equiv 0$”, that is, the consumer is in an evolutionary stable state at any time. When “$E_c + (1-a) \cdot F_{c2} > P_c + a \cdot F_{c1}$”, “$z = 1$” meets the equation steady state condition, the consumer will choose the “buying” strategy, and when “$E_c + (1-a) \cdot F_{c2} < P_c + a \cdot F_{c1}$” “$z = 0$”meets the equation steady state condition, the consumer will choose the “non-buying” strategy.

3 System dynamics simulation

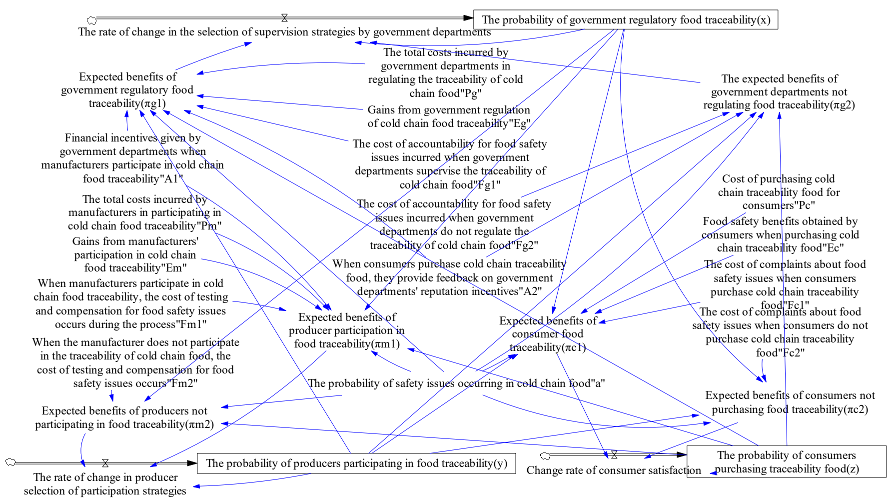
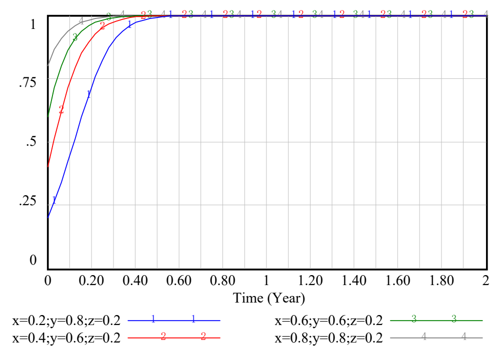


Fig. 1. A System Dynamics Model for Cold Chain Food Traceability

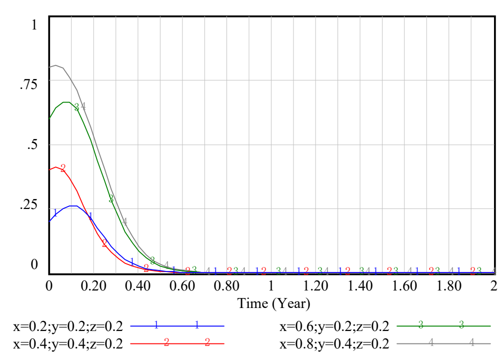
In this paper, the system dynamics simulation software Vensim is used to construct an SD model based on cold chain food traceability,as shown in Fig 1. The specific setting of parameters is based on the assignment of relevant studies [12,13]: P_g=20; P_m=45; P_c=15; E_g=40; E_m=50; E_c=20; A_1=10; A_2=20; a=0.7; F_{g1}=30; F_{g2}=35; F_{m1}=35; F_{m2}=45; F_{c1}=10; F_{c2}=20.

3.1 Simulation analysis of the stability of government department strategies

The initial policy probability of government departments was selected as x=0.2, x=0.4, x=0.6, x=0.8, and the corresponding four sets of data were selected for producers and consumers, and the influence of producer and consumer strategy probability on the stability strategy of government departments under different circumstances was analyzed. Fig.2(a,b) shows that when the value of "y" is greater than the critical value, the strategy of "x" is more inclined to "supervision" the traceability of cold-chain food, while the choice of "x" is inclined to the "non- supervision" strategy. In order to avoid economic losses to the greatest extent, manufacturers will be more inclined to "participation" in the traceability of cold-chain food, and use blockchain and Internet of Things technology to make cold-chain food information transparent. In order to make the healthy development of the cold chain food traceability industry, the "supervision" of government departments will be improved, so as to promote the establishment of a cold chain food traceability system.



$$a{:}\,y > \frac{P_g + a \cdot F_{g1} - E_g - (1-a) \cdot F_{g2}}{z(E_g + A_2 - P_g - a \cdot F_{g1}) - A_1}$$

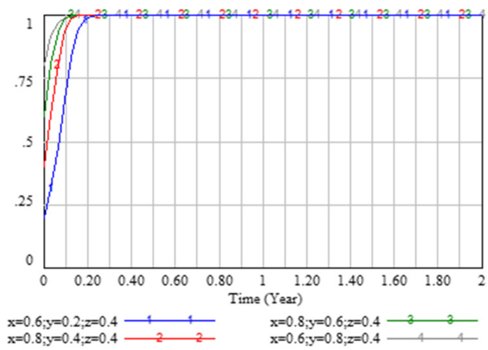


$$b{:}\,y < \frac{P_g + a \cdot F_{g1} - E_g - (1-a) \cdot F_{g2}}{z(E_g + A_2 - P_g - a \cdot F_{g1}) - A_1}$$

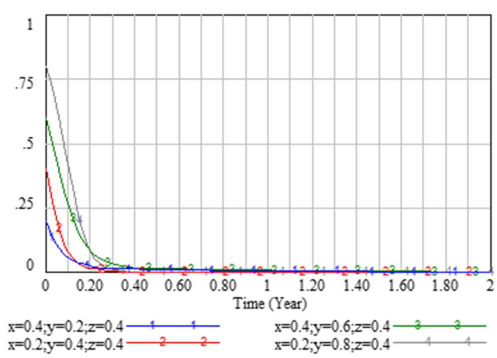
Fig. 2. The evolution results of different strategies by government departments with different values of "y"

3.2 Simulation analysis of the stability of the manufacturer's strategy

The initial strategy probability of the manufacturer was y=0.2, y=0.4, y=0.6, y=0.8, and the corresponding four sets of data were selected for the manufacturer and consumer, and the influence of the policy probability of government departments and consumers on the stability strategy of the manufacturer was analyzed under different circumstances. Fig.3(a,b) shows that when the value of “x” is greater than the critical value, the strategy choice of “y” is more inclined to “participation” in the traceability of cold chain food, while the choice of “y” is inclined to the “non-participation” strategy. As the source of cold chain food production, manufacturers should take into account both revenue and compensation issues, and when consumers buy cold chain food safety problems, not only complain about the manufacturer, but also reduce the credibility of government departments.



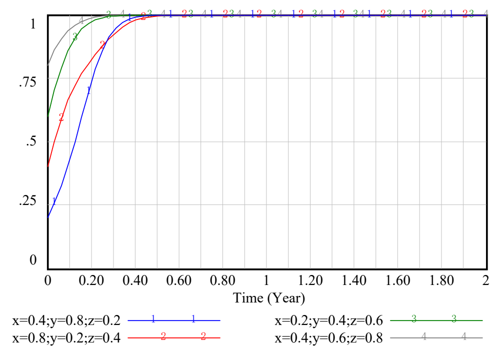
$$\text{a: } x > \frac{P_m + a \cdot F_{m1} - (1-a) \cdot F_{m2} - E_m}{A_1}$$



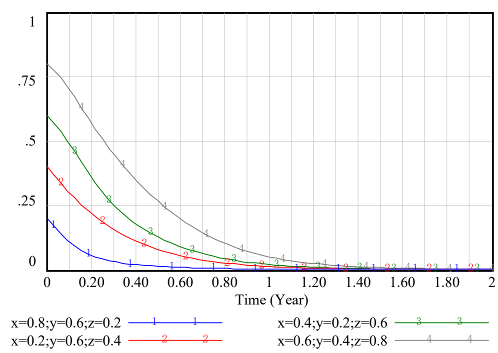
$$\text{b: } x < \frac{P_m + a \cdot F_{m1} - (1-a) \cdot F_{m2} - E_m}{A_1}$$

Fig. 3. The results of the evolution of different strategies of producers with different "x" values

3.3 Simulation analysis of consumer strategy stability



a: $E_c + (1-a) \cdot F_{c2} > P_c + a \cdot F_{c1}$



b: $E_c + (1-a) \cdot F_{c2} < P_c + a \cdot F_{c1}$

Fig. 4. When the cost and benefit are different, the evolution of different consumer strategies

The initial strategy probability of consumers was selected as z=0.2, z=0.4, z=0.6, z=0.8, and the corresponding four sets of data were selected for producers and consumers, and the impact of government departments and manufacturers' strategy probabilities on consumer stability strategies was analyzed under different circumstances. Fig4(a,b) shows that the influence of government departments and manufacturers on consumer strategy choice is small, and consumers, as special subjects, have a relatively simple thinking structure, when the cost of benefits is greater than the cost of expenditure, consumers will "buying" cold-chain traceable food, and vice versa, consumers will buy ordinary cold-chain food.

4 Conclusions

In this paper, the government departments, manufacturers, and consumers are the main body of the tripartite game, and a tripartite evolutionary game model based on the cold chain food traceability model is constructed. The results show that: Government departments should improve the relevant industry policies for the traceability of cold chain food, establish appropriate reward and punishment mechanisms, increase penalties on cold chain food safety issues, protect the rights and interests of consumers, and at the same time, should also strengthen the supervision of cold chain food data collection and processing, to prevent producer information tampering or false information into the traceability system; Manufacturers need to develop and operate cold chain food traceability systems. Improve the accuracy and timeliness of information in the production of cold chain food, introduce the Internet of Things and blockchain technology to ensure the authenticity and reliability of the traceability information provided; Consumers actively participate in the evaluation and supervision of the cold chain food traceability system, deepen the role of consumers in the game system, and reduce the supervision cost of all parties.

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