Current Research in Food Science 7 (2023) 100619

Contents lists available at ScienceDirect

Current Research in Food Science

journal homepage: www.sciencedirect.com/journal/current-research-in-food-science

Food manufacturer willingness to employ blockchain technology system under the social Co-governance framework: China's situation

Linhai Wu [a,b,*], Jiahui Chen [b], Xiaoting Dai [b], Xiujuan Chen [b], Jingxiang Zhang [c]

[a] *Institute for Food Safety Risk Management, Jiangnan University, Wuxi, China*
[b] *School of Business, Jiangnan University, Wuxi, China*
[c] *School of Science, Jiangnan University, Wuxi, China*

A R T I C L E I N F O

Handling Editor: Professor A.G. Marangoni

Keywords:
Food safety
Blockchain technology system
Enterprise behavior strategy
Evolutionary game
Social co-governance

A B S T R A C T

The blockchain technology system has gradually come to be employed in the food supply chain system, and it has emerged that the system offers the unique function of effectively curbing counterfeiting by food manufacturers. Unlike previous research on adoption by enterprises of new technology, this paper probes into the specific evolutionary routes of game subjects from the perspective of the precondition for enterprises' willingness to employ blockchain technology on the basis of China's social co-governance framework and by establishing a tripartite evolutionary game model of food manufacturer, government and consumer. The study then tests and verifies the stability conditions of equilibrium points and the relationship between these equilibrium points and the social co-governance level through numerical simulation analysis. On the above basis, the expected market proceeds of food producers employing blockchain technology and the influence of government and consumer behavior on enterprises' selection of a behavior strategy and the level of social co-governance are analyzed. The results show that every subject selects their own behavior strategy on the basis of the balance of their respective interests, and the final stability condition of the system is independent of their initial intentions. Rather, the expected sales volume of foods employing blockchain technology, governmental behavior (e.g., supervision, casual inspection, economic punishment, and fiscal subsidies), and complaints made by consumers constitute the main factors that influence food enterprises' selection of a behavior strategy. The level of social co-governance and the behavior of both government and consumers will ultimately be accomplished by influencing enterprises' expected economic returns, and the selection of an enterprise behavior strategy internally depends on the expected economic returns from producing foods employing blockchain technology. Therefore, this paper makes relevant proposals in an attempt to assist the Chinese government to better promote and popularize the blockchain technology system among food manufacturing enterprises.

1. Introduction

Having safe food to eat is a basic perquisite for the existence and development of human beings, and therefore, it is an issue of great concern worldwide (Xu et al., 2019; Duan et al., 2021). However, a zero-risk situation in food safety has never been achieved since the birth of human society, and now, food safety risk has evolved complicated characteristics such as being widely distributed, diversified in types, and hardly foreseeable, alongside known traditional risks like pesticide residue and unknown ones of new types brought by, for example, 3D printing technology (D. Chen et al., 2021).

Essentially, food safety risk mainly comes from three main sources. First, biological risks come from microbes and their metabolic products, which may produce toxins in the processing of food, parasites and their eggs, and insects and other food pollution (Fisher et al., 2012; Nerín et al., 2016). Second, physical risks can arise after eating foreign matter in bush meat, foraged food, or agricultural products. Physical risks can also arise after cross-contamination in the course of food processing (Sanlier, 2009). The third type of risk is chemical risk, which can arise from agricultural non-point-source pollution caused by use of chemical products (Abrahams, 2002) and from chemical pollution of the environment by industrial waste water, waste gas, and solid waste discharged from industrial activities (Udeigwe et al., 2015).

The above-mentioned risks are mainly attributable to natural factors,

* Corresponding author. Institute for Food Safety Risk Management, Jiangnan University, Wuxi, China.
E-mail address: wlh6799@126.com (L. Wu).

https://doi.org/10.1016/j.crfs.2023.100619
Received 31 July 2023; Received in revised form 10 October 2023; Accepted 17 October 2023
Available online 18 October 2023

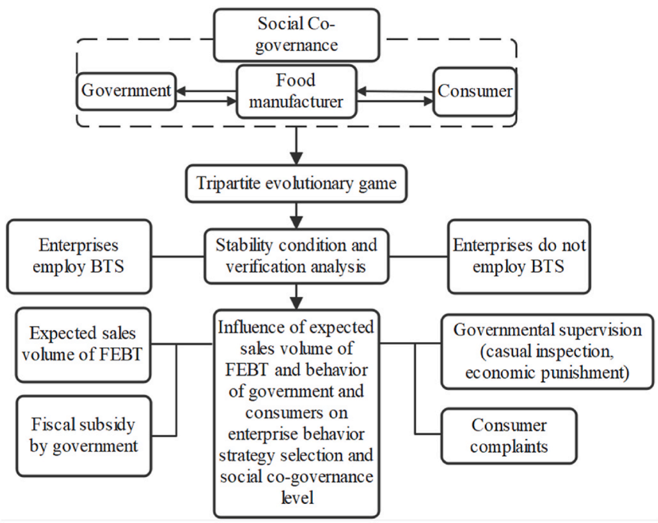

Fig. 1. Diagram of research method.

science and technology capacity, and the imperfect governance system. Food safety risks will also arise from human factors such as manufacturers and business operators. The pattern of the market economy, with competition as its fundamental characteristic, has long provided food manufacturers with incentives for moral hazards such as counterfeiting or adulteration (Bodo, 2019). As early as the beginning of the nineteenth century, food fraud had become very serious in the UK, peaking in the mid-nineteenth century (Collins, 1993; Engels, 2003). In the early twentieth century, food fraud was quite serious in the US, with different types being disguised and diversified (Niu et al., 2021). But this problem is not confined to Western market economies. After China implemented market-oriented reform starting in 1992, food fraud became rampant, reaching its highest point in the first decade of the 21st century with some particularly severe food fraud scandals such as the Fuyang Milk Powder Case and Melamine Milk Powder Case (Wu et al., 2017).

In order to regulate and reduce food fraud, the governments and social organizations of many countries, along with international organizations, have implemented measures to prevent food fraud, including introducing and updating legislation, carrying out strict and widespread crackdowns on food-related crimes, modernizing technological standards, establishing traceability systems, regulating industrial self-discipline, and exerting a market reputation mechanism. Overall, these efforts have yielded remarkable effects. For example, the US Food, Drug and Cosmetic Act (FD&C Act) played a significant role in controlling food counterfeiting (Law, 2004). However, food counterfeiting still happens frequently worldwide despite it being almost universally illegal.

Food safety is, in a sense, "produced." Therefore, food manufacturers can install in their food processing and manufacturing system a technical system that has functions such as accurately and securely recording and storing the information on the whole course of manufacturing and transmitting unalterable data openly and transparently, the chronic problem of food fraud may be solved by embedding access to such data in the co-governance system of government, market and society. Blockchain technology offers the capability to enact such a system.

The blockchain technological system is composed of a series of data blocks, which are protected by a public key and a private key and bear a timestamp. The blockchain technological system contains a distributed public ledger bearing unalterable transaction records (Ali et al., 2020), and through its use to date, the system has proven to be a significant technical breakthrough offering a way to effectively curb food fraud committed by enterprises. To examine blockchain's ability to reduce food fraud through data traceability and transparency, this study focuses on food fraud in China's market. An evolutionary game model is established on the basis of the social co-governance framework. This model is then used to examine (1) the evolution of behavior strategies selected by the government, the market, and consumers, (2) the stability conditions for the system to reach an equilibrium point, (3) the relationship between the equilibrium points and social co-governance level, and (4) the influence on enterprises' selection of a strategy for utilization of the blockchain technology system (BTS) of both the change or fluctuation in expected market sales volume of foods employing blockchain technology (FEBT), and the behaviors of government and consumers. Overall, the study aims to provide valuable information to help promote and popularize the BTS among enterprises, thereby helping to reduce food fraud.

2. Literature review

Food fraud has long been considered as a major worldwide public health hazard second only to drugs (C. L. Chen et al., 2021). Over the recent decade, the BTS, which provides technological support for controlling food fraud,[1] has emerged and been widely adopted around the world. Nakamoto (2008) set up a new-type electronic pay system, and for the first time, employed blockchain as the basic technology in building the data structure and encryption transmission of information (Osei et al., 2018). Since then, in order to overcome the shortcomings of mainstream digital currencies, such as the ease with which they can be hacked and customer privacy breached, hundreds of cryptocurrencies imitating Bitcoin have been issued worldwide, such as ETH (Ethereum), ADA (Cardano), and LTC (Litecoin), ushering in the BTS1.0 era (Wu and Tran, 2018). Subsequently, the finance industry has gradually come to employ BTS, represented by Smart Contracts and Ethereum, which stimulated the system to step into the 2.0 era (Kuo et al., 2017). Since 2014, the BTS has been increasingly adopted in the real economy, such as in food, agriculture, and health industries, initiating the 3.0 era (Li et al., 2020).

Blockchain technology is a distributed ledger technology that is mutually verifiable (Casino et al., 2019). It is a type of linked data structure composed of data block in order of time, characterized by decentralization, openness and transparency, an unalterable nature, and anonymity, among others (Lu, 2019; Feng et al., 2020). The decentralization of the BTS is realized by relying on a distributed network, encryption algorithm, and consensus mechanism; in addition, every participant in the system is equal, which plays an active role in breaking the information gap among subjects. This last trait in particular can stimulate the information communication and action in harmony among the subjects of social co-governance for food safety (Tao et al., 2022) and alleviate information asymmetry and the failure of the government and market (Alkhudary et al., 2022).

For example, after the introduction of a BTS into the food manufacturing system, information and data arising in the course of food production may be collected from production sites and transmitted to the blockchain system's database in real time through sensors. These initial data will be encrypted and form a data fingerprint through an asymmetric cryptographic algorithm. These data will then be

[1] The blockchain technology system can be introduced in the whole production process from raw material of food through processing and manufacturing to storage and logistics, and then to sale and consumption. In an attempt to provide a new approach for controlling counterfeiting by enterprises, this paper mainly examines the evolution of how food processing and manufacturing enterprises select a blockchain technology system from the perspective of management. Therefore, this paper neither elaborates the mechanism or process of the blockchain technology system's functioning to prevent food enterprises from counterfeiting, nor deals with the application of the blockchain technology system to the whole food supply chain system. In the following parts, this paper refers to the food processing and manufacturing enterprises as food manufacturers, food enterprises, or enterprises.

permanently stored in the BTS through the Byzantine Fault Tolerance Consensus Mechanism (Huan et al., 2022); any data alterations have to be conducted in accordance with the Smart Contract formulated jointly by the participating subjects (Hewa et al., 2021). The transparency of the entire food supply chain is thus improved, technological support is provided for preventing food fraud, and consumer confidence in food safety strengthened (da Silva and Moro, 2021). As research conducted in many different countries has shown, the BTS has been widely adopted in the manufacturing and processing of mangos, pork, turkey meat, dairy products, beer, beef, chicken, aquatic products, and many others, and has achieved remarkable effects (Peter, 2017).

On the basis of traditional methods of manufacturing foods, an enterprise has to make additional investments in order to produce FEBT (Garaus and Treiblmaier, 2021). This additional investment will be used mainly to procure production equipment; transform production flow and technology; optimize the production environment; pay human resource costs for technological innovation, daily management, and maintenance expenses; and pay costs required for utilization of the BTS (Da Xu et al., 2021; Venkatesh et al., 2020). For example, it is necessary to procure sensors to satisfy the requirements for transmission, processing, storage, display, recording, and control of information (Ripol-les-Avila et al., 2019), and develop new wireless sensor networks based on blockchain so as to ensure the safety, unalterable nature, and verifiability of the collected data (Dener and Orman, 2023).

Although their costs will increase by incorporating blockchain, enterprises will nonetheless obtain economic returns. For example, because food manufacturers will improve the accuracy of information traceability after employing the BTS (Seifermann et al., 2022), once any food safety accident occurs, the source of the problem may be identified through the tracing function of the BTS (Galvez et al., 2018) and recall costs can be lessened (Li et al., 2023). The BTS can store substantial amounts of information, which can assist enterprises to increase their decision-making efficiency, optimize their decision-making process, and improve the flexibility of their supply chain. This can help enterprises control productions costs (Wong et al., 2020).

However, enterprises are realists, so their willingness to employ BTS depends on the expected net economic proceeds, and an enterprise might rationally consider that the cost is more than could be recouped in case of a potentially rare incident, or further, if the enterprise intends to knowingly commit food fraud, such a system would be clearly against its self-interest. This is why blockchain to ensure food safety works best when embedded in a social co-governance function that places pressure on enterprises to adopt blockchain. For example, if, under the social co-governance framework, an enterprise produces risky foods, it will not only bear the economic punishment imposed by government, but the market revenue loss as a result of complaints by consumers[2] and loss of reputation. Only after considering all and costs and benefits and estimating that the expected proceeds from the production of FEBT will exceed the expected costs, will a firm employ the BTS.

The Technology Acceptance Model (TAM) is widely used to probe into the willingness of enterprises to employ new technology (Davis, 1986), and many studies conducted by China's scholars have employed TAM to examine the willingness of Chinese enterprises to adopt new technology. These studies have demonstrated that fiscal subsidies by the government and increases in demand can positively stimulate enterprises to employ new technology (Zhang, 2021).

Foods have the nature of quasi-public goods, and one of the government's responsibilities is to ensure food safety. Common methods used worldwide supervise and control enterprises include administrative, economic and judicial methods, as well as implementing technical standards of foods, popularizing new technology, introducing control regulations by enacting new laws and regulations, and perfecting fiscal policy as well. The EU and countries such as the US and Japan have, through legislation, banned foods not produced in a traceability system (Cattaneo et al., 2019).

The Hazard Analysis Critical Control Point (HACCP) is the international food quality safety control system (WHO, 1992). As early as 1995, the US Food and Drug Administration enacted regulations requiring marine product processors to implement HACCP (Ward and Hart, 1996). Therefore, enterprises' production behavior strategies are necessarily affected by government actions (Liu et al., 2022). When an enterprise cannot reconcile food quality and economic benefits, it is most likely to take an illegal moral hazard to secure excess profits (Jin et al., 2016). Therefore, governments have to utilize diversified measures to compel enterprises to produce safe foods.

Governments of Western countries also encourage food manufacturers, through fiscal subsidies, preferential tax policies, and other incentive policies, to employ new technology (Yu et al., 2022). As recently as the early 21st century, the Chinese government used fiscal subsidies to encourage enterprises to employ the traceability technology system, which played a significant role in ensuring the safety of pork and other edible agricultural products (Wu et al., 2010). Over the recent decade, the Chinese government has supervised and administered enterprises in accordance with laws and imposed strict economic punishment upon enterprises that produced risky foods, which greatly affected enterprise behaviors (Gao et al., 2023).

New consumption demand is significant to increase enterprises' willingness to employ new technology (Priem et al., 2012). For example, a traceability system may be connected with information on every section of the entire food supply chain, which transforms food safety from a credence attribute into a search attribute. Consumers are thus willing to pay higher prices for traceable foods, so the development of the traceable food market is stimulated (Violino et al., 2019). Wu et al. (2015) summarized the main reasons for the failure of China's food traceability system to make a breakthrough and be used by the majority of enterprises: government has not implemented an active, effective consumption policy, and due to insufficient consumption demand, enterprises are not willing to adopt the traceability system, which makes it difficult to effectively cultivate a market for traceable food.

Although the BTS has only recently been employed by the food manufacturing industry, many studies have probed the main factors influencing enterprises' willingness to employ the system. Bumblauskas et al. (2020), Casino et al. (2021), and Danese et al. (2021) used numerous cases to demonstrate that the BTS not only strengthens the traceability of the whole process of agricultural products, but also improves the quality perception among consumers, lowers the probability of production of risky agricultural products, and reduces the recall costs of agricultural products with risk problems. Lin et al. (2022) pointed out that compared with traditionally traceable beef, consumers are willing to pay higher prices for beef that is traceable through blockchain technology. In addition, Rodriguez-Salvador and Dopico (2020), Jin et al. (2023), and Li et al., (2023) considered that due to rising consumer income levels and improved knowledge about food safety science, demand for FEBT will be increased, which will stimulate enterprises to employ the BTS.

Wu et al. (2023) demonstrated that the willingness of every member of the food supply chain to employ a blockchain traceability system is related to the distribution of economic benefits and acceptance by consumers of FEBT. Kamble et al. (2020), Nayal et al. (2021), and Peng et al. (2022) hold that the method of governmental supervision and administration and the costs of investment constitute the key factors influencing enterprises' adoption of the BTS. It was also found that the blockchain system can satisfy the requirements of governmental supervision and administration as well as consumption demand, and also help enterprises improve their technological and management levels.

In summary, these aforementioned studies provide important background and context for the present paper. They also elucidate the gap this study seeks to fill: most research into the behavior strategy selection

[2] Governments impose many forms of punishments on enterprises that produce risky foods, but this paper only considers economic punishment.

of enterprises for employment of BTS were conducted from a single point of view, namely, enterprises, government, or market demand, and were therefore not comprehensive For example, when probing into the influence of governmental behavior on employment by enterprises employing a BTS, previous studies focused on the influence of fiscal subsidies, while paying little attention to the combined influence of fiscal subsidies and governmental supervision and administration.

In addition, the existing literature mainly examined Western countries, with little insight into China's situation. China has a substantially larger population than Western countries, and the daily food consumption amounts to 2 billion kg, which are mainly produced and supplied by small and medium-sized enterprises without sufficient technological capacity to employ blockchain. Furthermore, because of shortcomings in the legal and credit systems, moral hazard such as food fraud occurs frequently (Wu and Liu, 2023). In addition, with government as the main body and without sufficient social forces, China's governing system is not perfect, and research into enterprise behavior strategy selection is rarely included in the co-governance framework of government, market, and society.

Unlike previous research, the contribution by this paper lies in the following respects: (1) it focuses on China's situation, (2) it probes into the preconditions for enterprises' willingness to employ the BTS on the basis of the social co-governance framework, and (3) by establishing a tripartite evolutionary game model of enterprises, government, and consumers and by taking enterprises' expected economic returns from the employment of the BTS as a thread, this paper researches into the evolutionary routes of game subjects for strategy selection, the stability conditions for the system to reaching equilibrium points, and the relationship between these equilibrium points and the level of social co-governance through numerical simulation.

3. Methods

3.1. Research framework and general assumptions

From the 1970s, Western countries came to realize that social forces had unique functions that the government and market lacked (Garcia Martinez et al., 2013); only when a social co-governance system is formed with joint participation and efforts toward common goals by government, enterprises, non-governmental organizations, consumers, and so on, can the failure of both government and market be offset and enterprise behavior be influenced effectively (Cyphers and Schultz, 2019; Mutshewa, 2010). Since 2012, China has utilized social co-governance as a basic system for regulating food safety risks, and it has been proven that this basic system has achieved sound effects (Zhao and Tang, 2020). For the sake of simplicity, on the basis of the concept that the BTS has the function of decentralization and can ensure all participants are equal subjects, this paper builds a social co-governance system composed of government, enterprises, and consumers,[3] considers the behavior strategy of an enterprise under this social co-governance framework regarding whether to employ the BTS, establishes a tripartite evolutionary game model of government, enterprises, and consumers, and probes into the evolutionary routes of game subjects for strategy selection and the game equilibrium points. The research method is shown in Fig. 1.

Undoubtedly, although enterprises, the government, and consumers have a common desire for ensuring food safety, every game subject has its own interest and limited rationality. In the beginning period, their behavior strategy is not their optimum choice, but rather a relatively equilibrium status that evolved and in response to the operating environment. Because business operations and the sense of social responsibility vary among manufacturers, and because China has not imposed compulsory requirements by law to employ blockchain technology, the set of the strategies used by enterprises for employing the BTS is {employ, not employ temporarily}.[4]

In China, local governments bear responsibility for food safety in areas under their respective jurisdiction. However, local governments have wide remits concerning economic development and social governance, and their limited local financial revenues must be carefully allocated and prioritized. Therefore, governments have two options: {support, suspend support temporarily}. Generally speaking, those FEBT are sold in market at prices higher than those of ordinary foods. The food consumption methods of Chinese consumers are diversified, but consumption is determined internally by their scientific cognition of food safety and income levels, a process similar to those in Western countries (Zhu et al., 2023). Therefore, the behavior strategy of consumers contains two options: {buy FEBT, buy ordinary foods}. In consideration of the foregoing, this paper makes the following assumption, with the parameter descriptions shown in Table 1.

Assumption 1. The set of the strategies of enterprises for employing the BTS is {employ, not employ temporarily}, and the corresponding probabilities are x and $1-x$, respectively, with $0 \le x \le 1$. If an enterprise chooses to produce FEBT, it is assumed that the additional investment in technology, equipment, and human resources and the increased daily maintenance expenses after employment of BTS are equal to C_1 (total expected costs). It is also assumed that the enterprise will increase its operating efficiency after employment of the BTS and can easily recall any foods if a food safety accident occurs. Accordingly, the expected cost reductions enjoyed by the enterprise are denoted C_2.[5]

The expected sales value of the FEBT is W_1. Thus, the expected return from production of FEBT is $W_1 - C_1 + C_2$. If the enterprise chooses not to employ the BTS temporarily, it is assumed that the expected sales value from production of ordinary foods is W_2. Because of the difference in production methods, the probability of producing risky foods will vary between firms employing blockchain technology and those producing ordinary foods; these probabilities are denoted g_1 and g_2, respectively, and their values can be expressed as follows: $0 < g_1 < g_2 < 1$.

Assumption 2. The set of behavior strategy options for local government with respect to supporting enterprises to employ the BTS is {support, suspend support temporarily}, and the corresponding probabilities are y and $1-y$, respectively, with $0 \le y \le 1$. When support is chosen,

[3] The food supply chains' composition is extremely complicated, and the supply chain system varies across different types of food, but they all contain at least behavior subjects such as raw material manufacturers and suppliers, food manufacturers and processors, and dealers. In consideration of the fact that the blockchain technology system is mainly employed by manufacturers and processors (called manufacturers or enterprises hereinafter), this paper brings only manufacturers into the tripartite evolutionary game model. In addition, the composition of social forces is complicated, generally including industrial associations, news media and other social organizations, and consumers. Similarly, for the sake of simplicity, this paper brings only consumers into the model.

[4] In this paper, if an enterprise employs the blockchain technology system to produce foods, the foods so produced are called "foods employing blockchain technology," and it is considered that all foods produced by this enterprise are "foods employing blockchain technology"; otherwise, the foods produced not employing the system are called ordinary foods, and all the foods produced by this enterprise are ordinary foods.

[5] According to the Food Safety Law of the People's Republic of China currently in force, when a food producer and dealer finds that any food made or dealt in by it is not up to the food safety standard or, as evidenced, may do harm to health, such producer must stop production and operation and then recall the food that has been put into market for sale and dispose of them in time; and thus the costs of enterprises will increase. If an enterprise employs the blockchain technology system, it will effectively reduce the probability of food safety accident, and once such accident occurs, the related foods can be recalled effectively soon.

Table 1
Parameters and description.

Parameter notation	Explanation
C_1	Total of the additional investment in introduction of technology, equipment, and human resources required for employment of the BTS and the increased daily maintenance expenses after employment of the BTS.
C_2	Expected costs reduced by the enterprise therefore as a result of its employment of the BTS.
C_3	Expected governmental expenses decreased because government supports the employment of the BTS by enterprises.
C_4	Expected increased costs of searching for information of the foods made by other manufacturers, which arise when an enterprise produces FEBT but consumers buy ordinary foods or when an enterprise produces ordinary foods but consumers buy FEBT.
W_1	Expected sales value of the FEBT produced by enterprises.
W_2	Expected sales value of the ordinary foods produced by enterprises.
R_1	Sum of expected financial revenues increased because government supports employment of the BTS by enterprises.
R_2	Expected award by the government for a complaint by a consumer after the complaint is confirmed true by the government.
S_1	Consumer surplus of a consumer buying FEBT.
S_2	Consumer surplus of a consumer buying ordinary foods.
G	Governmental fiscal subsidy expected to be obtained by enterprises.
D_1	When the government chooses to suspend support of employment of the BTS temporarily, financial revenues decrease therefore, and the expected costs and expenses of increased daily supervision and administration expenses and recalling of food with safety problem total D_1.
D_2	Expected economic loss to be incurred by an enterprise because of the loss of market reputation after a consumer reports complaint and the government confirms it true.
D_3	When an enterprise produces FEBT but consumers buy ordinary foods, or an enterprise produces ordinary foods but consumers buy FEBT, the enterprise loses part of its expected market return because of the loss of such consumers, which totals is D_3.
g_1	Probability of production by enterprises of risky FEBT
g_2	Probability of production of ordinary foods by enterprises
g_3	Probability of random inspection of enterprises by government
g_4	Probability of a consumer making a complaint to the government after buying risky foods
F	Sum of economic punishment imposed by the government on enterprises that produce risky foods

government will encourage enterprises through a fiscal subsidy, and it is assumed that the governmental subsidy and other expected benefits obtained by enterprises as a result is G. With government support, many enterprises employed the BTS and therefore improved the local protection of food safety. The local investment environment was boosted as well, and the government's financial revenues thus increased; the increased sum of financial revenues is denoted R_1.

Due to their employment of the BTS, enterprises lower the probability of production of risky foods, which in turn decreases the costs and expenses of daily governmental supervision and administration; even if any food safety accident does occur, the fiscal spending incurred in response will also be decreased.[6] The expected governmental expense decreases as a result are denoted C_3, and the probability of an enterprise undergoing a random inspection by the government is g_3. When an enterprise is found to have produced risky food, the government imposes an economic punishment according to the law, and the value of this punishment is F; this means that the enterprise is fined g_1g_3F by the government. Meanwhile, an enterprise that produces risky ordinary foods is fined g_2g_3F by the government. When a local government chooses to suspend support temporarily, the local protection of food safety cannot be improved effectively, and the investment environment is likely to worsen; it is assumed that financial revenues decrease. The expected cost and increased daily supervision, administration, and recalls of food with safety problem is denoted as D_1.

Assumption 3. The set of consumer behavior strategy options toward foods is: {buy FEBT, buy ordinary foods}, and the corresponding probabilities are z and $1 - z$, with $0 \leq z \leq 1$. Generally speaking, the willingness to pay (WTP) of consumers refers to the highest price a consumer will pay for foods; however, because a consumer has to pay actual market prices when buying food, a gap exists between the highest prices a consumer is willing to pay and the actual paid prices. This gap is called the consumer surplus. It is assumed that the consumer surplus when buying FEBT and ordinary foods is S_1 and S_2, respectively. Because the former is less risky and bears more transparent quality information than the latter, which upgrades the acceptance of consumers regarding the foods, the result can be expressed as $S_1 > S_2$.

It is assumed that the probability of a consumer making a complaint to the government after buying risky foods is g_4, and the expected award from the government after confirming the complaint is true is R_2. Then, the award from the government for such a complaint is $g_2g_4R_2$, and the relevant enterprise will bear an expected economic loss of D_2 as a result of the loss of market reputation. Thus, the expected returns for a consumer buying FEBT and ordinary foods are $S_1 + g_1g_4R_2$ and $S_2 + g_2g_4R_2$, respectively. When an enterprise produces FEBT but consumers buy ordinary foods because of their cognition or spending power, or when an enterprise produces ordinary foods but consumers buy FEBT, the enterprise loses part of its expected market return because of the loss of such consumers. This lost expected market return is D_3, and the expected increased costs of searching for information on foods from other manufacturers is C_4.[7]

On the basis of the above assumptions and the game relationship among enterprises, government, and consumers, the payoff matrix of the tripartite game is developed as shown in Table 2.

3.2. Model calculation and analysis of evolutionary routes

This section will solve the replicated dynamic equation of enterprises, government, and consumers, respectively, on the basis of the payoff matrix in the Table 2, and analyze the stability strategy of every participant on the basis of the theory of differential equations.

3.2.1. Replicated dynamic equation of tripartite behavior strategy selection

The symbols U_{11}, U_{12}, and $\overline{U_1}$ represent the expected returns of an enterprise from production of FEBT and foods not employing blockchain technology, and the average expected returns, respectively. The replicated dynamic equation of an enterprise's behavior strategy selection is $F(x)$. Then on the basis of Table 2, Expressions (1), (2), and (3), and the

[6] According to the Food Safety Law of the People's Republic of China in force, once a food safety accident occurs, the competent supervision authority must carry out investigation into the responsibility immediately, seal up the related foods, and bear the expenses arising therefrom.

[7] The costs of searching for information refers to the value of searching arising from price dispersion in the free competition market. From the perspective of cost accounting, its unit of measurement must be the same as that of traditional costs, namely, money.

Table 2
Payoff matrix of tripartite game.

Strategy combination	Enterprises	Government	Consumer
(Employ, support, buy FEBT)	$W_1 - C_1 + C_2 - g_1g_3F + G - g_1g_4D_2$	$g_1g_3F - G + R_1 + C_3 - g_1g_4R_2$	$S_1 + g_1g_4R_2$
(Employ, support, buy ordinary foods)	$W_1 - C_1 + C_2 - g_1g_3F + G - g_1g_4D_2 - D_3$	$g_1g_3F - G + R_1 + C_3 - g_2g_4R_2$	$S_2 + g_2g_4R_2 - C_4$
(Employ, suspend support temporarily, buy FEBT)	$W_1 - C_1 + C_2 - g_1g_3F - g_1g_4D_2$	$g_1g_3F + C_3 - D_1 - g_1g_4R_2$	$S_1 + g_1g_4R_2$
(Employ, suspend support temporarily, buy ordinary foods)	$W_1 - C_1 + C_2 - g_1g_3F - g_1g_4D_2 - D_3$	$g_1g_3F + C_3 - D_1 - g_2g_4R_2$	$S_2 + g_2g_4R_2 - C_4$
(Not employ temporarily, support, buy FEBT)	$W_2 - g_2g_3F - g_2g_4D_2 - D_3$	$g_2g_3F - g_1g_4R_2$	$S_1 + g_1g_4R_2 - C_4$
(Not employ temporarily, support, buy ordinary foods)	$W_2 - g_2g_3F - g_2g_4D_2$	$g_2g_3F - g_2g_4R_2$	$S_2 + g_2g_4R_2$
(Not employ temporarily, suspend support temporarily, buy FEBT)	$W_2 - g_2g_3F - g_2g_4D_2 - D_3$	$g_2g_3F - D_1 - g_1g_4R_2$	$S_1 + g_1g_4R_2 - C_4$
(Not employ temporarily, suspend support temporarily, buy ordinary foods)	$W_2 - g_2g_3F - g_2g_4D_2$	$g_2g_3F - D_1 - g_2g_4R_2$	$S_2 + g_2g_4R_2$

replicated sub-dynamic equation of enterprises shown in Equation (4) can be generated.

$$U_{11} = yz(W_1 - C_1 + C_2 - g_1g_3F + G - g_1g_4D_2) + y(1-z)(W_1 - C_1 + C_2 - g_1g_3F + G - g_1g_4D_2 - D_3) + (1-y)z(W_1 - C_1 + C_2 - g_1g_3F - g_1g_4D_2) + (1-y)(1-z)(W_1 - C_1 + C_2 - g_1g_3F - g_1g_4D_2 - D_3) \tag{1}$$

$$U_{12} = yz(W_2 - g_2g_3F - g_2g_4D_2 - D_3) + y(1-z)(W_2 - g_2g_3F - g_2g_4D_2) + (1-y)z(W_2 - g_2g_3F - g_2g_4D_2 - D_3) + (1-y)(1-z)(W_2 - g_2g_3F - g_2g_4D_2) \tag{2}$$

$$\overline{U_1} = xU_{11} + (1-x)U_{12} \tag{3}$$

$$F(x) = dx/dt = x(U_{11} - \overline{U_1}) = x(1-x)(yG + W_1 - C_1 + C_2 - g_1g_3F - W_2 + g_2g_3F - g_1g_4D_2 + g_2g_4D_2 - D_3 + 2zD_3) \tag{4}$$

The symbols U_{21}, U_{22}, and $\overline{U_2}$ represent the government's expected returns from support and temporary suspension of support to enterprises employing the BTS and average expected returns, respectively. The replicated dynamic equation of the government's behavior strategy selection is $F(y)$. Then, on the basis of Table 2, Expressions (5), (6), and (7), and the replicated sub-dynamic equation of government shown in Equation (8) can be generated.

$$U_{21} = xz(g_1g_3F - G + R_1 + C_3 - g_1g_4R_2) + x(1-z)(g_1g_3F - G + R_1 + C_3 - g_2g_4R_2) + (1-x)z(g_2g_3F - g_1g_4R_2) + (1-x)(1-z)(g_2g_3F - g_2g_4R_2) \tag{5}$$

$$U_{22} = xz(g_1g_3F + C_3 - D_1 - g_1g_4R_2) + x(1-z)(g_1g_3F + C_3 - D_1 - g_2g_4R_2) + (1-x)z(g_2g_3F - D_1 - g_1g_4R_2) + (1-x)(1-z)(g_2g_3F - D_1 - g_2g_4R_2) \tag{6}$$

$$\overline{U_2} = yU_{21} + (1-y)U_{22} \tag{7}$$

$$F(y) = dy/dt = x(U_{21} - \overline{U_2}) = y(1-y)(-xG + xR_1 + D_1) \tag{8}$$

The symbols U_{31}, U_{32}, and $\overline{U_3}$ represent consumers' expected returns from buying FEBT and ordinary foods and the average expected returns, respectively. The replicated dynamic equation of consumers' behavior strategy selection is $F(z)$. Then, on the basis of Table 2, Expressions (9), (10), and (11), and the replicated sub-dynamic equation of consumers shown in Equation (12) can be generated.

$$U_{31} = xy(S_1 + g_1g_4R_2) + x(1-y)(S_1 + g_1g_4R_2) + (1-x)y(S_1 + g_1g_4R_2 - C_4) + (1-x)(1-y)(S_1 + g_1g_4R_2 - C_4) \tag{9}$$

$$U_{32} = xy(S_2 + g_2g_4R_2 - C_4) + x(1-y)(S_2 + g_2g_4R_2 - C_4) + (1-x)y(S_2 + g_2g_4R_2) + (1-x)(1-y)(S_2 + g_2g_4R_2) \tag{10}$$

$$\overline{U_3} = zU_{31} + (1-z)U_{32} \tag{11}$$

$$F(z) = dz/dt = z(U_{31} - \overline{U_3}) = z(1-z)(S_1 + g_1g_4R_2 - S_2 - g_2g_4R_2 - C_4 + 2xC_4) \tag{12}$$

On the basis of the above three replicated sub-dynamic Equations (4), (8) and (12), the tripartite replicated dynamic equation shown in Expression (13) is generated.

$$\begin{cases} F(x) = x(1-x)\begin{pmatrix} yG + W_1 - C_1 + C_2 - g_1g_3F - W_2 + g_2g_3F - g_1g_4D_2 \\ + g_2g_4D_2 - D_3 + 2zD_3 \end{pmatrix} \\ F(y) = y(1-y)(-xG + xR_1 + D_1) \\ F(z) = z(1-z)(S_1 + g_1g_4R_2 - S_2 - g_2g_4R_2 - C_4 + 2xC_4) \end{cases} \tag{13}$$

3.2.2. *Analysis of evolutionary route of food manufacturers*

According to the stability theory differential equation, to reach a stable probability that an enterprise will employ the BTS, the following preconditions must be satisfied: $F(x) = 0$ and $F'(x) = d(F(x))/dx < 0$. When the following formula is established: $z = z^* = (-yG - W_1 + C_1 - C_2 + g_1g_3F + W_2 - g_2g_3F + g_1g_4D_2 - g_2g_4D_2 + D_3)/2D_3$, then $F'(x) = 0$, and every x is in evolutionary stability. When $z > z^*$, then $F'(1) < 0$, and $x = 1$ is the evolutionary stability strategy, which means that the enterprise chooses to employ the BTS. However, when $z < z^*$, then $F'(0) < 0$, and $x = 0$ is the evolutionary stability strategy, which means that the enterprise chooses not to employ the blockchain technology strategy temporarily. The evolutionary phase diagram of the enterprise behavior strategy is shown in Fig. 2, in which the arrow represents the orientation of evolution of x toward 0 and 1.

3.2.3. *Analysis of evolutionary routes of government*

Similarly, to reach a stabile probability of government support for enterprises' employment of the BTS, the following preconditions must be satisfied: $F(y) = 0$ and $F'(y) = d(F(y))/dy < 0$. When $x = x^* = D_1/(G - R_1)$, $F'(y) = 0$, every y is in evolutionary stability; when $x > x^*$, then $F'(0) < 0$, $y = 0$ is the evolutionary stability strategy, which means that government chooses to support; when $x < x^*$, $F'(1) < 0$, $y = 1$ is the evolutionary stability strategy, which means that government chooses to suspend support temporarily. The evolutionary phase diagram of the government behavior strategy is shown in Fig. 3, in which the arrow represents the orientation of evolution of y toward 0 and 1.

3.2.4. *Analysis of evolutionary routes of consumers*

To reach a stabile probability of consumers buying FEBT, the following preconditions must be satisfied: $F(z) = 0$ and $F'(z) = d(F(z))/dz < 0$. When $x = x^{*'} = (-S_1 - g_1g_4R_2 + S_2 + g_2g_4R_2 + C_4)/2C_4$, then $F'(z) = 0$, and every z is in evolutionary stability; when $x > x^{*'}$, then $F'(1) < 0$, $z = 1$ is the evolutionary stability strategy, which means that consumers choose to buy FEBT; when $x < x^{*'}$, then $F'(0) < 0$, $z = 0$ is the evolutionary stability strategy, which means that consumers choose to buy ordinary foods. The evolutionary phase diagram of the

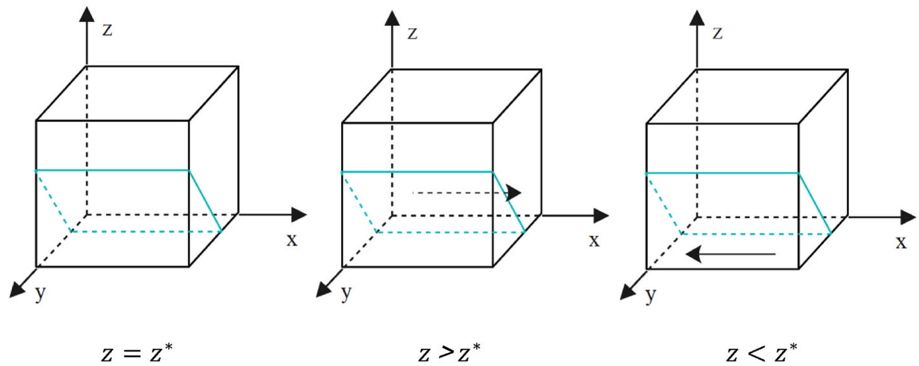

Fig. 2. Evolutionary phase diagram of food manufacturer behavior strategies.

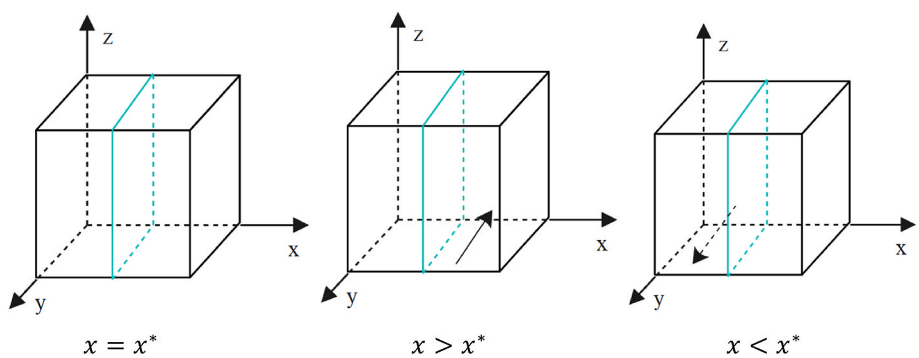

Fig. 3. Evolutionary phase diagram of government behavior strategy.

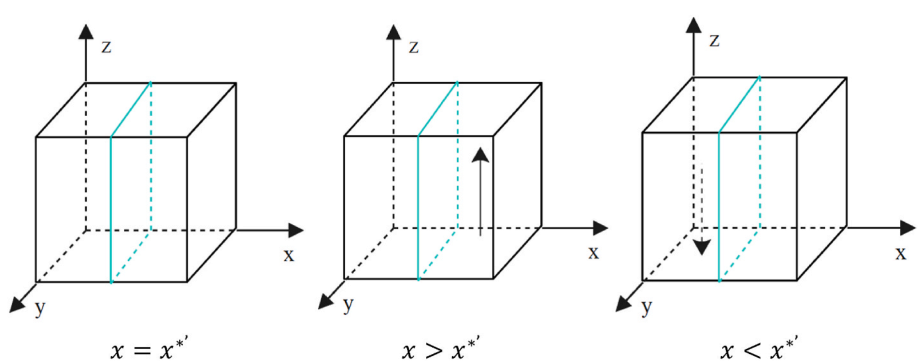

Fig. 4. Evolutionary phase diagram of consumer behavior strategy.

consumer behavior strategy is shown in Fig. 4, in which the arrow represents the orientation of evolution of z toward 0 and 1.

3.3. Analysis of stability of evolutionary game equilibrium points

If $dx/dt = 0$, $dy/dt = 0$, and $dz/dt = 0$ in the replicated dynamic equation (13), then there are eight equilibrium points (E_1 (0,0,0), E_2 (0,0,1), E_3 (0,1,0), E_4 (0,1,1), E_5 (1,0,0), E_6 (1,0,1), E_7 (1,1,0), and E_8 (1,1,1)) on the 3D space $V = \{(x,y,z)|0 \le x \le 1, 0 \le y \le 1, 0 \le z \le 1\}$.

According to the stability theory of Lyapunov (Parks, 1992), when all the characteristic values (λ) of Jacobian matrix are less than zero, the equilibrium point is of asymptotic stability. When all the characteristic values (λ) of the Jacobian matrix exceed zero, the equilibrium point is not stable. If the values of λ are both positive and negative, the equilibrium point is the saddle point. In order to analyze the asymptotic stability of the equilibrium points, the value of λ is calculated according to the following formula (14):

$$J = \begin{bmatrix} \partial F(x)/\partial x & \partial F(x)/\partial y & \partial F(x)/\partial z \\ \partial F(y)/\partial x & \partial F(y)/\partial y & \partial F(y)/\partial z \\ \partial F(z)/\partial x & \partial F(z)/\partial y & \partial F(z)/\partial z \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{14}$$

$$= \begin{bmatrix} (1-2x)\begin{pmatrix} yG + W_1 - C_1 \\ +C_2 - g_1g_3F - W_2 \\ +g_2g_3F - g_1g_4D_2 \\ +g_2g_4D_2 - D_3 + 2zD_3 \end{pmatrix} & x(1-x)G & x(1-x)2D_3 \\ y(1-y)(-G+R_1) & (1-2y)\begin{pmatrix} -xG + xR_1 \\ +D_1 \end{pmatrix} & 0 \\ z(1-z)2C_4 & 0 & (1-2z)\begin{pmatrix} S_1 + g_1g_4R_2 \\ -S_2 - g_2g_4R_2 \\ -C_4 + 2xC_4 \end{pmatrix} \end{bmatrix}$$

The values of λ calculated with formula (14) are shown in Table 3.

It can be known from the Table 3 that the characteristic values (λ_{i2}) of E_1 (0,0,0) and E_2 (0,0,1) are more than zero, are unstable points, and cannot reach the stable condition. Therefore, this paper does not conduct a demonstrative analysis of stability.

4. Conclusion and discussion

4.1. Verification of preconditions for stability of equilibrium points and relationship between equilibrium points and social Co-governance level

The stability preconditions for every equilibrium point in Table 3 were tested and verified through numerical simulation of the tripartite evolutionary routes using Matlab software. E_1 (0,0,0) and E_2 (0,0,1) are two unstable points, and E_3 (0,1,0), E_4 (0,1,1), E_5 (1,0,0), E_6 (1,0,1), E_7 (1,1,0), and E_8 (1,1,1) are the equilibrium points of enterprises' choices to employ or not employ the BTS. According to the foregoing research assumptions and Table 3, we set the parameter values of every equilibrium points as shown in Table 4, and on this basis, we conduct a numerical simulation for every equilibrium point.

4.1.1. Preconditions for stability of equilibrium points of the enterprises' strategy to not employ the BTS

Because the values of every parameter in Table 4 satisfy conditions (1) and (2) listed in Table 3, the initial intention of enterprises, the government, and consumers may be set at (0.3,0.4,0.9), (0.5,0.6,0.7), and (0.2,0.5,0.8), respectively. Their selection of a behavior strategy under different initial intentions was simulated, and the result is shown in Figs. 5 and 6. The results indicate that the initial intention of the behavior strategy of enterprises, government, and consumers finally evolved into E_3 (0,1,0), and E_4 (0,1,1), respectively, namely, {not employ temporarily, support, buy ordinary foods},{not employ temporarily, support, buy FEBT}, which indicates that the final stable status of the system is not influenced by the initial intention of each subject, but the initial intention does affect the time required for the system to evolve to an equilibrium point: it takes a subject with a stronger initial intention less time to evolve into the stable status than those with a weaker initial intention.

4.1.2. Preconditions for stability of equilibrium points of the strategy of enterprises to employ the BTS

Because the values of every parameter set in Table 4 satisfy conditions (3), (4), (5), and (6) listed in Table 3, the initial intention of enterprises, the government, and consumers may be set at (0.3,0.4,0.9), (0.5,0.6,0.7), and (0.2,0.5,0.8), respectively. The simulation was accordingly carried out, and the result are shown in Figs. 7–10. The results indicate that the initial intention of the behavior strategy of enterprises, government, and consumers finally evolved into E_5 (1,0,0), E_6 (1,0,1), E_7 (1,1,0), and E_8 (1,1,1), namely, {employ, suspend support temporarily, buy ordinary foods},{employ, suspend support temporarily, buy FEBT}, {employ, support, buy ordinary foods}, and {employ, support, buy FEBT}. This indicates that the system's final stability is related only to the preconditions for its stability, and not the participants' respective initial intentions. Rather, the initial intention of behavior only affects the time required for the system to evolve into an equilibrium point.

4.1.3. Relationship between equilibrium points and social Co-governance level

Social co-governance for food safety risk has numerous aspects, with diversified forms of co-governance. For the purpose of this paper, it is defined as the processes, institutions, regulations, decisions, and activities by which the government, enterprises, and consumers control food safety risks jointly within the scope of costs they can bear, respectively, so as to ensure a proper level of food safety. In the social co-governance system composed of government, enterprises, and consumers, every subject chooses their individual behavior strategy on the basis of the balance of their respective interests and protection of their common interest in food safety, and then the social co-governance system thus reaches equilibrium in the repeated evolutionary game. The preceding analysis has indicated that the overall system's equilibrium point is realized not through maximum participation effort by every subject in social co-governance, but through balance among their respective

Table 3
Analysis of characteristic values of the System's equilibrium points and stability.

Equilibrium points	Characteristic values			Preconditions for stability
	λ_{i1}	λ_{i2}	λ_{i3}	
$E_1(0,0,0)$	$W_1 - C_1 + C_2 - g_1g_3F - W_2 + g_2g_3F - g_1g_4D_2 + g_2g_4D_2 - D_3$	D_1	$S_1 + g_1g_4R_2 - S_2 - g_2g_4R_2 - C_4$	Unstable points or saddle points
$E_2(0,0,1)$	$W_1 - C_1 + C_2 - g_1g_3F - W_2 + g_2g_3F - g_1g_4D_2 + g_2g_4D_2 + D_3$	D_1	$-S_1 - g_1g_4R_2 + S_2 + g_2g_4R_2 + C_4$	Unstable points or saddle points
$E_3(0,1,0)$	$G + W_1 - C_1 + C_2 - g_1g_3F - W_2 + g_2g_3F - g_1g_4D_2 + g_2g_4D_2 - D_3$	$-D_1$	$S_1 + g_1g_4R_2 - S_2 - g_2g_4R_2 - C_4$	Precondition (1)
$E_4(0,1,1)$	$G + W_1 - C_1 + C_2 - g_1g_3F - W_2 + g_2g_3F - g_1g_4D_2 + g_2g_4D_2 + D_3$	$-D_1$	$-S_1 - g_1g_4R_2 + S_2 + g_2g_4R_2 + C_4$	Precondition (2)
$E_5(1,0,0)$	$-W_1 + C_1 - C_2 + g_1g_3F + W_2 - g_2g_3F + g_1g_4D_2 - g_2g_4D_2 + D_3$	$-G + R_1 + D_1$	$S_1 + g_1g_4R_2 - S_2 - g_2g_4R_2 + C_4$	Precondition (3)
$E_6(1,0,1)$	$-W_1 + C_1 - C_2 + g_1g_3F + W_2 - g_2g_3F + g_1g_4D_2 - g_2g_4D_2 - D_3$	$-G + R_1 + D_1$	$-S_1 - g_1g_4R_2 + S_2 + g_2g_4R_2 - C_4$	Precondition (4)
$E_7(1,1,0)$	$-G - W_1 + C_1 - C_2 + g_1g_3F + W_2 - g_2g_3F + g_1g_4D_2 - g_2g_4D_2 + D_3$	$G - R_1 - D_1$	$S_1 + g_1g_4R_2 - S_2 - g_2g_4R_2 + C_4$	Precondition (5)
$E_8(1,1,1)$	$-G - W_1 + C_1 - C_2 + g_1g_3F + W_2 - g_2g_3F + g_1g_4D_2 - g_2g_4D_2 - D_3$	$G - R_1 - D_1$	$-S_1 - g_1g_4R_2 + S_2 + g_2g_4R_2 - C_4$	Precondition (6)

Precondition (1)–(6): $\lambda_{i1}, \lambda_{i2}, \lambda_{i3} < 0$

Table 4
Equilibrium points and assignment for every parameter.

Parameters	Equilibrium points					
	E_3 (0,1,0)	E_4 (0,1,1)	E_5 (1,0,0)	E_6 (1,0,1)	E_7 (1,1,0)	E_8 (1,1,1)
C_1	9	8	6	4	4	8
C_2	1	1	3	1	2	1
C_3	1	1	1	1	1	1
C_4	1	1	1	1	1	1
W_1	3	1	3	3	1	3
W_2	2	3	1	2	1	2
R_1	2	2	1	1	2	2
R_2	10	20	40	10	40	10
S_1	2	5	2	2	2	2
S_2	1	1	1	1	1	1
G	2	2	3	3	2	3
D_1	2	2	1	1	2	2
D_2	20	20	20	20	20	20
D_3	2	1	1	2	1	1
g_1	0.3	0.3	0.3	0.3	0.3	0.3
g_2	0.5	0.5	0.5	0.5	0.5	0.5
g_3	0.5	0.4	0.5	0.5	0.5	0.5
g_4	0.5	0.5	0.5	0.5	0.5	0.5
F	20	10	20	20	20	20

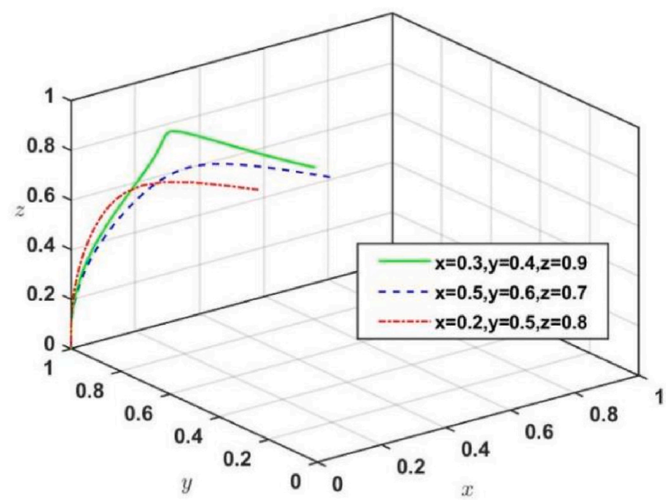

Fig. 5. Equilibrium point E3 (0,1,0) stability test.

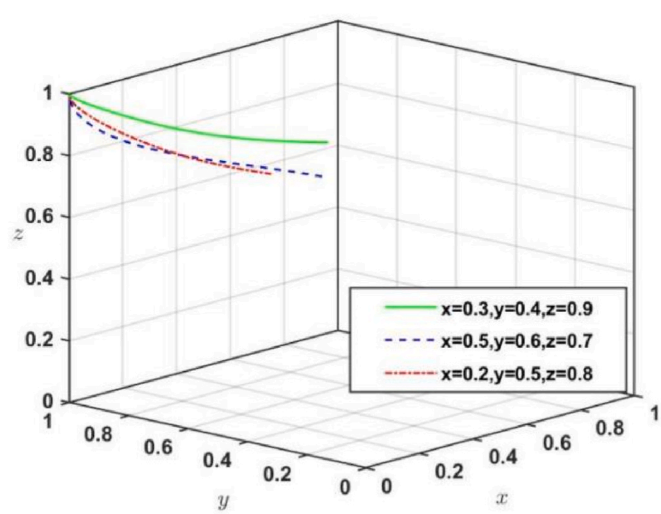

Fig. 6. Equilibrium point E_4 (0,1,1) stability test.

behavior strategies. For example, at the equilibrium point E_5 (1,0,0), the set of behavior strategies followed by enterprises, government, and consumers is {employ, suspend support temporarily, buy ordinary foods}, which means that government and consumers, on the basis of consideration of their interests, choose to suspend the fiscal subsidy temporarily and buy ordinary foods, respectively, and the system is kept at an equilibrium point while the social co-governance stays at a relatively low level. The other five equilibrium points, including E_3 (0,1,0), E_4 (0,1,1), E_6 (1,0,1), E_7 (1,1,0), and E_8 (1,1,1), represent different levels of social co-governance. The evolution process of the system from E_3(0,1,0) or E_5 (1,0,0) toward E_8 (1,1,1) is in fact an evolution of the behavior strategy followed by the government, enterprises, and consumers from inconsistency into consistency and from low similarity to high similarity in orientation.

4.2. *Influence of expected sales volume of FEBT and behavior of government and consumers on enterprise behavior strategy selection and social Co-governance level*

The analysis presented in the preceding sections has demonstrated the preconditions for equilibrium point stability under the circumstances of enterprises determining to employ or not employ temporarily the BTS, together with the relationship between each equilibrium point and corresponding social co-governance level. Because E_1 (0,0,0) and E_2 (0,0,1) are two unstable points, this paper did not deal with them. We mainly examine the influence of the expected sales volume of FEBT, governmental behavior (fiscal subsidy, economic punishment, and probability of casual inspection) and consumer behavior (probability of complaints about risky foods and enterprises' resulting expected loss) upon the enterprises' choice of behavior strategy and social co-governance, taking E_3 (0,1,0) as the initial equilibrium point. In other words, we research how the above-mentioned change of related parameters affects the evolution from the equilibrium point E_3 (0,1,0) to E_8 (1,1,1).

4.2.1. Influence of expected sales volume of FEBT

While other parameters remaining unchanged, it is assumed that at the equilibrium point of E_3 (0,1,0), the initial intention of subjects $x_0=y_0=z_0=0.5$, and the expected sales value of FEBT $W_1 = 1, 2, 3, 4$. The corresponding evolutionary routes for the strategy selection of every subject are shown in Fig. 11. It can be found that at time $W_1 = 1$, enterprises, the government, and consumers choose to not employ temporarily, to provide a fiscal subsidy, and to buy ordinary foods, which means the lowest level of social co-governance. When W_1 rises to 2, although every subject still chose their original respective behavior strategy, and the system did not experience qualitative change but remained at the equilibrium point E_3 (0,1,0), it was found that the evolution of enterprises choosing not to employ the system temporarily clearly became slow. When W_1 increased to 3, the initial selection of behavior strategy of enterprises and consumers changed from those made at W_1: they now chose to employ the system and buy FEBT.

It was further found that the selection of a behavior strategy by enterprises, government, and consumers began to move toward the same orientation from this point. The system began to exhibit qualitative change and reached equilibrium point E_8 (1,1,1) and the social co-governance reached its highest level. With the further increase of W_1 to 4, although the selection of behavior strategy by enterprises, government, and consumers remained the same as at $W_1 = 3$ and the system remained at the equilibrium point E_8 (1,1,1), the evolution of enterprise' selection of employing the system became faster. The simulation results indicate that with other conditions remaining unchanged and with the expected sales volume of FEBT increasing, the economic returns of enterprises producing FEBT increase accordingly, and the willingness of the enterprises to employ the system is strengthened as a result.

4.2.2. Influence of level of fiscal subsidy by government

Under the condition that the other parameters remain unchanged, it is assumed that the expected subsidy ($G = 1,2,3,3.5$) provided by government in could take forms such as a tax reduction or exemption or a fiscal subsidy. The evolution of the resulting behavior strategies selected by each subject are shown in Fig. 12. It can be found that when $G = 1$, namely, when the system is at the equilibrium point E_3 (0,1,0), enterprises, the government, and consumers choose not to employ the system temporarily, to provide a fiscal subsidy, and to buy ordinary foods, respectively, and social co-governance is at the lowest level. When the government increases the fiscal subsidy, namely, $G = 2$, although the

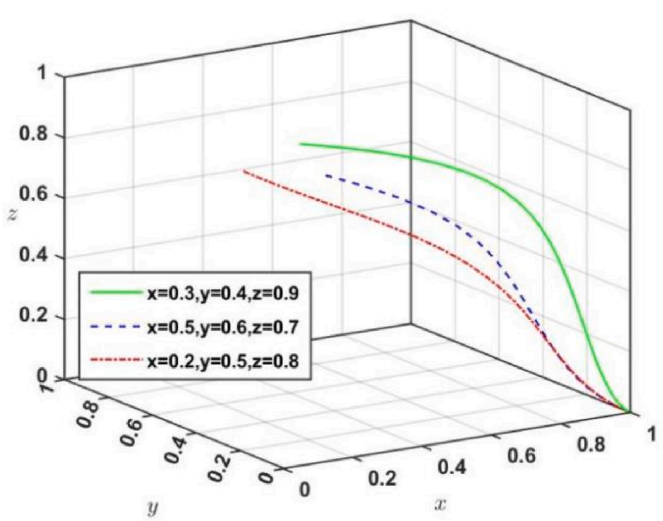

Fig. 7. Equilibrium point E_5 (1,0,0) stability test.

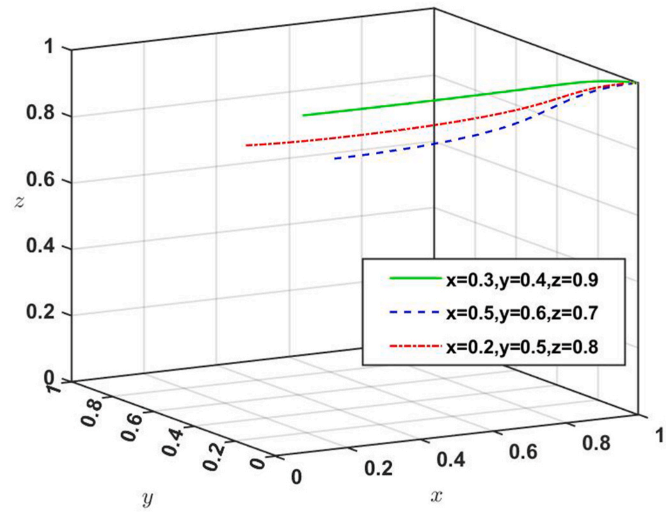

Fig. 8. Equilibrium point E_6 (1,0,1) stability test.

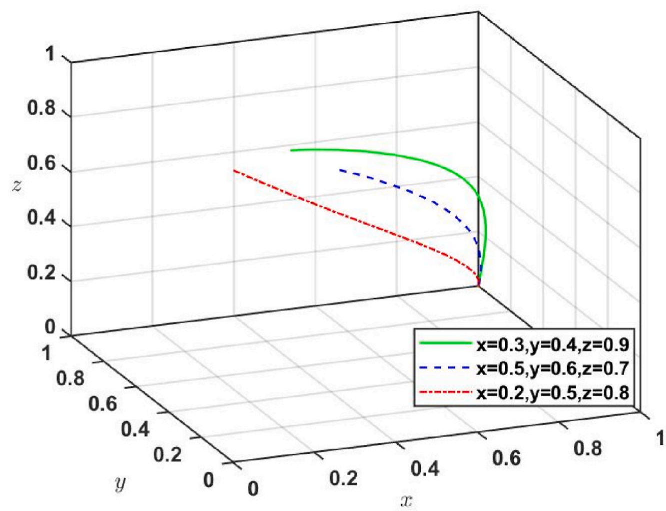

Fig. 9. Equilibrium point E_7 (1,1,0) stability test.

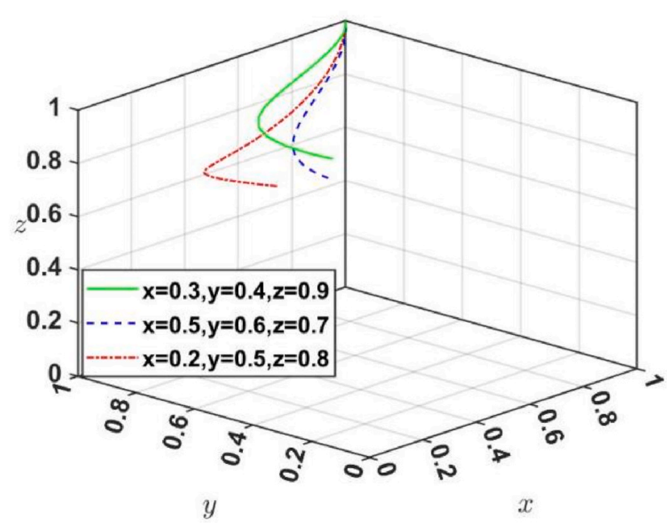

Fig. 10. Equilibrium point E_8 (1,1,1) stability test.

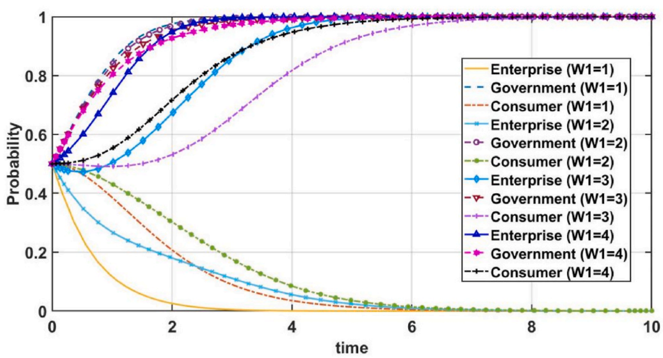

Fig. 11. Influence of W_1 on behavior strategy.

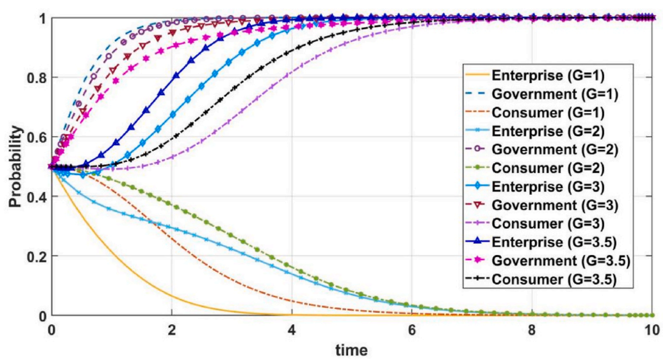

Fig. 12. Influence of G on behavior strategy.

behavior strategy selected by each subject remains unchanged and the system did not experience qualitative change but remained at the equilibrium point E_3 (0,1,0), the evolution of enterprises toward the strategy of not employing the system clearly slowed down. When government continues to increase the fiscal subsidy ($G = 3$), the behavior strategy selection of enterprises and consumers evolved into employment of the BTS and buying FEBT; at this point, the system is experiencing qualitative change and reached equilibrium point E_8 (1,1,1), with social co-governance at its highest level. If the governmental fiscal subsidy increases further, namely, at $G = 3.5$,[8] the behavior strategy selected by enterprises, government, and consumers remained the same as at the point of $G = 3$ and the system remained at the equilibrium point E_8 (1,1,1), but the evolution of the enterprise behavior strategy becomes faster.

4.2.3. Influence of governmental economic punishment

According to existing Chinese laws and regulations, the government can impose a range of sums to punish enterprises producing risky foods, and government bodies may exercise their respective discretionary power in the light of the extent of actual and potential risks and impose economic punishment accordingly. It is assumed that, on the condition that other parameters remain unchanged, the sum (F) of economic punishment imposed by government bodies due to the production of risky foods is $F = 5$, 10, 20, and 25. The evolutionary routes of the resulting behavior strategy selected by each subject are shown in Fig. 13. It can be found that when $F = 5$, namely when the system is at the equilibrium point E_3 (0,1,0), enterprises, the government, and

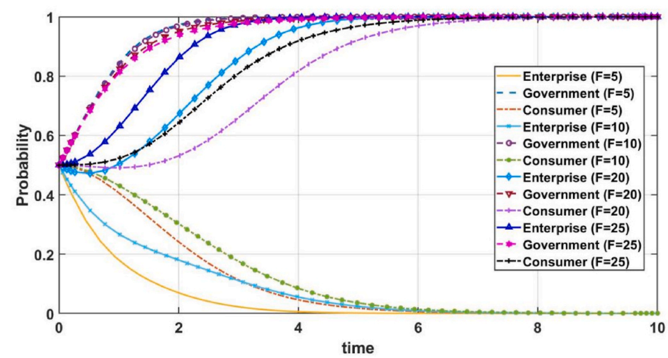

Fig. 13. Influence of F on behavior strategy.

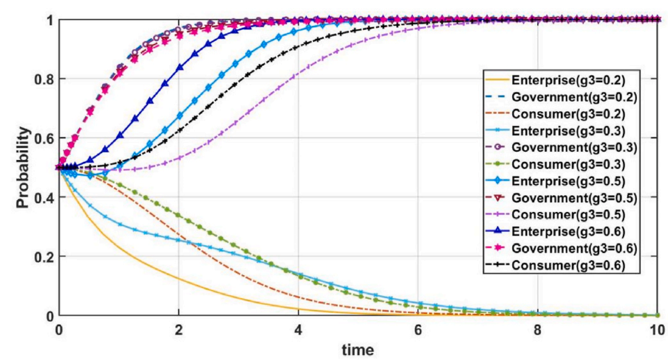

Fig. 14. Influence of g_3 on Behavior Strategy.

consumers choose the behavior strategy not to employ the system temporarily, to provide a fiscal subsidy, and to buy ordinary foods, respectively, and social co-governance is at the lowest level. When government strengthens the economic punishment, namely, $F = 10$, the behavior strategy selection of every subject remains unchanged, and the system has not experienced qualitative change and remains at E_3 (0,1,0), but the evolution of enterprises toward the strategy of not employing the system has slowed.

At $F = 20$, the behavior strategy selection of enterprises and consumers evolved into employment of BTS and buying FEBT, respectively; at this point, the system is experiencing qualitative change and has reached the equilibrium point E_8 (1,1,1), with social co-governance at its highest level. At $F = 25$, the selection of strategy by every subject remains the same as at the point of $F = 20$, and the system is still at the equilibrium point E_8 (1,1,1), but the evolution of enterprise behavior strategy is faster.

4.2.4. Influence of probability of governmental casual inspection

Similarly, under the condition that the other parameters remain unchanged and the probability of casual inspection by government of enterprises is assumed as $g_3 = 0.2$, 0.3, 0.5, and 0.6, the resulting evolutionary routes of the behavior strategy selected by every subject are shown in Fig. 14. At $g_3 = 0.2$, namely, when the system is at the equilibrium point E_3 (0,1,0), enterprises, the government, and consumers choose not to employ the system temporarily, to provide a fiscal subsidy, and to buy ordinary foods, respectively, and social co-governance is at the lowest level. When the probability of casual inspection by the government is increased to $g_3 = 0.3$, although the behavior strategy selection of every subject remains unchanged and the system has not experienced qualitative change but remains at the equilibrium point E_3 (0,1,0), the evolution of enterprise choosing not to employ the system temporarily slows down. At $g_3 = 0.5$, the behavior strategy selection of enterprises and consumers has, respectively, evolved into employment of the BTS and buying FEBT. At this point, the

[8] At $G = 4$, the probability of choice of strategy of support by government is 0.83; because this paper focuses on whether enterprises choose the behavior strategy of employing the blockchain technology system, and in fact, there is no excessive fiscal subsidy by government, the assigned value of 3.5 here is proper.

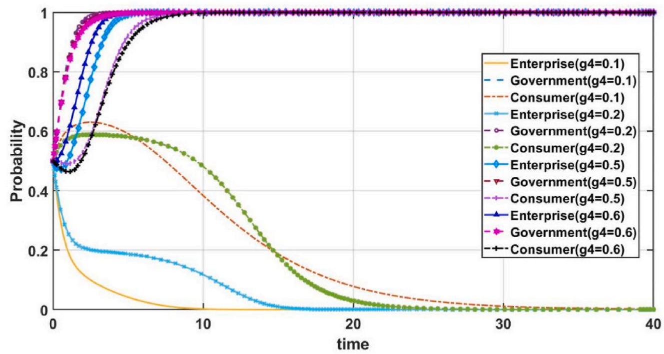

Fig. 15. Influence of g_4 on Behavior Strategy.

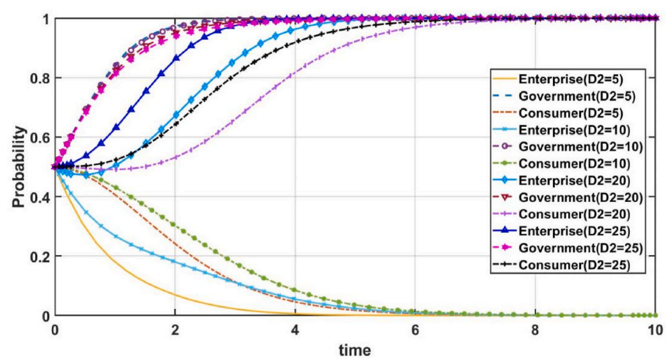

Fig. 16. Influence of D_2 on behavior strategy.

system experiences qualitative change and has evolved into the equilibrium point E_8 (1,1,1), with social co-governance at its highest level. At $g_3 = 0.6$, although the behavior strategy selection of each subject has not changed compared with those at $g_3 = 0.5$, the system is still at the E_8 (1,1,1).

4.2.5. *Influence of strength of consumer complaints*

Under the condition that the other parameters remain unchanged, the probability of a complaint by consumers is assumed as $g_4 = 0.1$, 0.2, 0.5, and 0.6. The evolution of the behavior strategy selection by every subject with the fluctuation of g_4 is shown in Fig. 15. At $g_4 = 0.1$, namely, when the system is at the equilibrium point E_3 (0,1,0), enterprises, the government, and consumers choose the behavior strategy to not employ the system temporarily, to provide a fiscal subsidy, and to buy ordinary foods, respectively, and social co-governance is at the lowest level. When $g_4 = 0.2$, although the behavior strategy selection of every subject remains unchanged and the system has not experienced qualitative change and remains at the equilibrium point E_3 (0,1,0), the evolution of enterprise choosing not to employ the system shows a clear temporary slowdown. With g_4 increasing continuously, the behavior strategy selected by enterprises and consumers evolves, respectively, into employment of the BTS and buying FEBT. At this point, the system experiences qualitative change and has evolved into the equilibrium point of E_8 (1,1,1), with social co-governance rising to its highest level.

Fig. 16 show the cases when the expected economic loss of an enterprise arising from complaints by consumers is ($D_2 = 5,10,20,25$).With D_2 increasing continuously, the behavior strategy selection of enterprises and consumers has, respectively, evolved from not employing the BTS and buying ordinary foods into employment of BTS and buying FEBT, the evolution of enterprises' behavior strategy toward stability is accelerated continuously, and social co-governance rises from the lowest to the highest level.

In summary, with the other parameters remaining unchanged, the expected sales value of FEBT, the strength of governmental behavior (fiscal subsidy, economic punishment, and supervision and casual inspection), and the probability of consumer complaints have a positive effect on enterprise behavior strategy selection and social co-governance level.

5. Main conclusion and policy implications

This paper examines how the selection of a behavior strategy by three subjects, including enterprises, government, and consumers, evolved on the basis of China's situation and establishing the social co-governance framework. The evolution was modeled by building the tripartite evolutionary game model, and the stability conditions of equilibrium points of the system and the relation between the equilibrium points and the level of social co-governance were tested, analyzed, and verified. Then, taking E_3 (0,1,0) as the initial equilibrium point, this paper analyzes the influence of (1) expected sales value of FEBT, and (2) government and consumer behavior on both enterprise behavior strategy selection and the level of social co-governance. In general, in the tripartite game system composed of enterprises, the government, and consumers, every subject chooses their respective behavior strategy on the basis of the balance of their own interests and protection of the common interest of food safety. The result of the model indicates that that the initial intention of each subject only affects the time required for e the system to evolve to a stable status, which means that the stronger the initial intention is, the less time the system needs to evolve to a stable status. In addition, the system's final stability is independent of the actors' initial intention, which means that their initial intention will not affect their selection of a behavior strategy. The evolution of the system from E_3 (0,1,0) into the optimum equilibrium point E_8 (1,1,1) is actually a trajectory of the game of subjects selecting of their behavior strategy from inconsistency to consistency and from low similarity in orientation to high similarity, which results in an upgrade of social co-governance as well.

Whether an enterprise is willing to produce FEBT is internally dependent on the game of behavior strategy selection of three parties, including enterprises, government, and consumers, namely, whether their respective selection is toward the same orientation and the system can reach an equilibrium point. This research has demonstrated that when other conditions remain unchanged, if any one of the following conditions evolves to a certain level, the behavior strategy selected by enterprises and the speed of behavior evolution will be affected:

(1) When the expected sales volume of FEBT increases continuously, the corresponding economic returns will also increase, and the intention of employing BTS by enterprises, which are in pursuit of economic benefits, will become intensified.
(2) When the government increases the probability of casual inspection or strengthens economic punishment, enterprises producing risky foods will face economic punishment imposed by the government, and the willingness of enterprises to employ the BTS will be increased accordingly in order to reduce the probability of production of risky foods and cut internal management costs. When the government increases its fiscal subsidy, the expected economic return from production of FEBT will be increased, and thus the willingness of enterprises to employ the BTS will be increased accordingly.
(3) When the probability of consumer complaints is increased, the loss of expected economic proceeds resulting from an enterprise's loss of market reputation will increase, and similarly, the speed of selection and the evolution enterprises' behavior strategy will change as well.
(4) Governmental behavior, including an increased probability of casual inspection, economic punishment, and fiscal subsidy, and consumer behavior, like an increased probability of complaints, influence the behavior strategy selection by enterprises by affecting enterprises' expected economic benefits. Internally, the

selection by enterprises of their behavior strategy is dependent on the expected economic proceeds from production of FEBT.

(5) There will be many equilibrium points in the evolution of the system, which represent different states of equilibrium in the game of behavior strategy selection of enterprises, the government, and consumers. A state of equilibrium represents a certain level of social co-governance.

As mentioned previously, HACCP is an internationally recognized technological security system adopted for assessing and controlling food risks. Because the BTS has a unique function, it is expected to become an important technical means similar to HACCP. For the purposes of China's situation, it is of great significance to popularize the BTS among food manufacturers. By analyzing the model's results from the perspective of management, the conclusions made in this paper have the following policy implications:

(1) The decisive function of the market mechanism must be brought into full play, and enterprises' internal motives for employing the BTS must be stimulated by increasing the economic benefits from producing FEBT.
(2) The government must take the initiative on the basis of actual conditions to strengthen fiscal subsidies, perform its responsibility for supervision and administration in accordance with the relevant rules and standards, impose punishment on enterprises producing risky foods according to laws, and influence enterprises' willingness to employ the BTS by utilizing economic methods.
(3) Chinese consumers' consciousness of participation in social co-governance is consistently relatively weak, which reflects the particular fact that they occupy the end of the food supply chain system. It also reflects the fact that for a long period, consumers have consistently regarded themselves as onlookers of food safety (Qin et al., 2022). Therefore, it is necessary to improve the scientific cognition of consumers, support consumer complaints about risky foods, and encourage consumers to expand their consumption of FEBT within their consumption power, so as to stimulate more enterprises to employ the BTS.
(4) In order to popularize the employment of the BTS among enterprises, it is necessary to exert the unique, irreplaceable function of enterprises, the government, and consumers, and focus more on synergy among their selected behavior strategies so as to stimulate the subjects to move toward more similar orientations and realize the relative equilibrium of the system.

The research for this paper is based on China's situation, but it may be used for reference with respect to popularization of the BTS among food manufacturers worldwide because the model developed in this paper is based on the expected proceeds of FEBT as an assumption, which is in conformity with the general rules of market economy, and the social co-governance system established therein is a governance system accepted and implemented in common by China and Western countries. However, this study also has limitations. For example, the research assumptions are based on Chinese situation, and the research was conducted on the basis of China's current conditions. However, differences exist between China and other countries in terms of food safety administration system, laws and regulations, consumption values, and so on. In China, for example, although most consumers care about food safety, they are less likely to officially report initial or one-off concerns, which differs sharply from the case in Western countries. Therefore, assessing and comparing the general applicability of this paper's conclusions to other contexts is a valuable and rich area of future research.

Three further key areas have emerged from this paper for future research. First, the research could be expanded to the whole food supply chain, including the willingness by all subjects to employ the system, i.e., not only manufacturers, but also producers and suppliers of raw materials, processors and manufacturers, and vendor and seller enterprises, so as to stimulate employment of the BTS among the whole system and impel the social co-governance system to achieve the preconditions for equilibrium points. Second, an extensive survey could be conducted of Chinese enterprises, along with an empirical study of selected typical samples, so as to demonstrate the scientific rigor and validity of this paper's conclusions. Third, comparative research could be carried out on the influence of using BTS by enterprises in countries other than China, so as to elucidate the common characteristics as well as any differences and demonstrate the general applicability of this paper's conclusions.

CRediT authorship contribution statement

Linhai Wu: Investigation, Supervision, Writing – review & editing. **Jiahui Chen:** Conceptualization, Formal analysis, Software, Validation, Writing – original draft. **Xiaoting Dai:** Methodology, Visualization. **Xiujuan Chen:** Writing – review & editing. **Jingxiang Zhang:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgement

Funding: This work was supported by the National Social Science Fund of China: Research on social co-governance of food safety risks and cross-border cooperative governance mechanism [grant numbers 20 & ZD117].

References

Abrahams, P.W., 2002. Soils: their implications to human health. Sci. Total Environ. 291 (1–3), 1–32. https://doi.org/10.1016/S0048-9697(01)01102-0.
Ali, O., Ally, M., Dwivedi, Y., 2020. The state of play of blockchain technology in the financial services sector: a systematic literature review. Int. J. Inf. Manag. 54, 102199 https://doi.org/10.1016/j.ijinfomgt.2020.102199.
Alkhudary, R., Queiroz, M.M., Féniès, P., 2022. Mitigating the risk of specific supply chain disruptions through blockchain technology. Supply Chain Forum: Int. J. Taylor & Francis 1–11. https://doi.org/10.1080/16258312.2022.2090273.
Bodo, T., 2019. Rapid urbanisation: theories, causes, consequences and coping strategies. Ann. Geogr. Stud. 2 (3), 32–45. https://doi.org/10.22259/2642-9136.0203005.
Bumblauskas, D., Mann, A., Dugan, B., Rittmer, J., 2020. A blockchain use case in food distribution: do you know where your food has been? Int. J. Inf. Manag. 52, 102008 https://doi.org/10.1016/j.ijinfomgt.2019.09.004.
Casino, F., Dasaklis, T.K., Patsakis, C., 2019. A systematic literature review of blockchain-based applications: current status, classification and open issues. Telematics Inf. 36, 55–81. https://doi.org/10.1016/j.tele.2018.11.006.
Casino, F., Kanakaris, V., Dasaklis, T.K., Moschuris, S., Stachtiaris, S., Pagoni, M., Rachaniotis, N.P., 2021. Blockchain-based food supply chain traceability: a case study in the dairy sector. Int. J. Prod. Res. 59 (19), 5758–5770. https://doi.org/10.1080/00207543.2020.1789238.
Cattaneo, C., Lavelli, V., Proserpio, C., Laureati, M., Pagliarini, E., 2019. Consumers' attitude towards food by-products: the influence of food technology neophobia, education and information. Int. J. Food Sci. Technol. 54 (3), 679–687. https://doi.org/10.1111/ijfs.13978.
Chen, C.L., Shang, X., Tsaur, W.J., Weng, W., Deng, Y.Y., Wu, C.M., Cui, J., 2021. An anti-counterfeit and traceable management system for brand clothing with hyperledger fabric framework. Symmetry 13 (11), 2048. https://doi.org/10.3390/sym13112048.
Chen, D., Li, J., Zhao, Y., Wu, Y., 2021. Human exposure of fipronil insecticide and the associated health risk. J. Agric. Food Chem. 70 (1), 63–71. https://doi.org/10.1021/acs.jafc.1c05694.
Collins, E.J., 1993. Food adulteration and food safety in Britain in the 19th and early 20th centuries. Food Pol. 18 (2), 95–109. https://doi.org/10.1016/0306-9192(93)90018-7.

Cyphers, L.A., Schultz, C.A., 2019. Policy design to support cross-boundary land management: the example of the Joint Chiefs Landscape Restoration Partnership. Land Use Pol. 80, 362–369. https://doi.org/10.1016/j.landusepol.2018.09.021.
da Silva, C.F., Moro, S., 2021. Blockchain technology as an enabler of consumer trust: a text mining literature analysis. Telematics Inf. 60, 101593 https://doi.org/10.1016/j.tele.2021.101593.
Da Xu, L., Lu, Y., Li, L., 2021. Embedding blockchain technology into IoT for security: a survey. IEEE Internet Things J. 8 (13), 10452–10473. https://doi.org/10.1109/JIOT.2021.3060508.
Danese, P., Mocellin, R., Romano, P., 2021. Designing blockchain systems to prevent counterfeiting in wine supply chains: a multiple-case study. Int. J. Oper. Prod. Manag. 41 (13), 1–33. https://doi.org/10.1108/IJOPM-12-2019-0781.
Davis, F.D., 1986. A Technology Acceptance Model for Empirically Testing New End-User Information Systems, vol. 17. Cambridge, MA. http://hdl.handle.net/1721.1/15192.
Dener, M., Orman, A., . BBAP-WSN: a new blockchain-based authentication protocol for wireless sensor networks. Appl. Sci. 13 (3), 1526. https://doi.org/10.3390/app13031526.
Duan, X., Meng, Q., Fei, X., Lin, M., Xiao, R., 2021. The impacts of farmland loss on regional food self-sufficiency in Yangtze River delta urban agglomeration over last two decades. Rem. Sens. 13 (17), 3514. https://doi.org/10.3390/rs13173514.
Engels, F., 2003. The condition of the working class in England. Am. J. Publ. Health 93 (8), 1246–1249. https://doi.org/10.2105/AJPH.93.8.1246.
Feng, H., Wang, X., Duan, Y., Zhang, J., Zhang, X., 2020. Applying blockchain technology to improve agri-food traceability: a review of development methods, benefits and challenges. J. Clean. Prod. 260, 121031 https://doi.org/10.1016/j.jclepro.2020.121031.
Fisher, M.C., Henk, D.A., Briggs, C.J., Brownstein, J.S., Madoff, L.C., McCraw, S.L., Gurr, S.J., 2012. Emerging fungal threats to animal, plant and ecosystem health. Nature 484 (7393), 186–194. https://doi.org/10.1038/nature10947.
Galvez, J.F., Mejuto, J.C., Simal-Gandara, J., 2018. Future challenges on the use of blockchain for food traceability analysis. TrAC, Trends Anal. Chem. 107, 222–232. https://doi.org/10.1016/j.trac.2018.08.011.
Gao, H., Dai, X., Wu, L., Zhang, J., Hu, W., 2023. Food safety risk behavior and social Co-governance in the food supply chain. Food Control 152, 109832. https://doi.org/10.1016/j.foodcont.2023.109832.
Garaus, M., Treiblmaier, H., 2021. The influence of blockchain-based food traceability on retailer choice: the mediating role of trust. Food Control 129, 108082. https://doi.org/10.1016/j.foodcont.2021.108082.
Garcia Martinez, M., Verbruggen, P., Fearne, A., 2013. Risk-based approaches to food safety regulation: what role for co-regulation? J. Risk Res. 16 (9), 1101–1121. https://doi.org/10.1080/13669877.2012.743157.
Hewa, T., Ylianttila, M., Liyanage, M., 2021. Survey on blockchain based smart contracts: applications, opportunities and challenges. J. Netw. Comput. Appl. 177, 102857 https://doi.org/10.1016/j.jnca.2020.102857.
Huan, M., Ding, Z., Li, S., Zhang, C., 2022. Blockchain Consensus Mechanism Design for Food Safety Traceability. Intell. Autom. Soft Co. Springer International Publishing, pp. 620–627. https://doi.org/10.1007/978-3-030-81007-8_70.
Jin, S., Cao, Y., Jones, G., Li, W., Frewer, L.J., 2023. Consumers' purchase intentions towards traced foods: a comparative analysis between the United Kingdom and China. Food Control 152, 109828. https://doi.org/10.1016/j.foodcont.2023.109828.
Jin, Y., Meng, Y., Xu, Y., Xie, F., 2016. A study on what cause the lack of integrity in China's food companies. In: Food Hygiene, Agriculture and Animal Science: Proceedings of the 2015 International Conference on Food Hygiene, Agriculture and Animal Science, pp. 136–144. https://doi.org/10.1142/9789813100374_0018.
Kamble, S.S., Gunasekaran, A., Sharma, R., 2020. Modeling the blockchain enabled traceability in agriculture supply chain. Int. J. Inf. Manag. 52, 101967 https://doi.org/10.1016/j.ijinfomgt.2019.05.023.
Kuo, T.T., Kim, H.E., Ohno-Machado, L., 2017. Blockchain distributed ledger technologies for biomedical and health care applications. J. Am. Med. Inf. Assoc. 24 (6), 1211–1220. https://doi.org/10.1093/jamia/ocx068.
Law, M., 2004. In: Whaples, Robert (Ed.), History of Food and Drug Regulation in the United States. EH. Net Encyclopedia, edited by. October 11.
Li, K., Lee, J.Y., Gharehgozli, A., 2023. Blockchain in food supply chains: a literature review and synthesis analysis of platforms, benefits and challenges. Int. J. Prod. Res. 61 (11), 3527–3546. https://doi.org/10.1080/00207543.2021.1970849.
Li, Q., Zhou, W., Wang, Q., Fu, D., 2023. Research on online nondestructive detection technology of duck egg origin based on visible/near-infrared spectroscopy. Foods 12 (9), 1900. https://doi.org/10.3390/foods12091900.
Li, X., Jiang, P., Chen, T., Luo, X., Wen, Q., 2020. A survey on the security of blockchain systems. Future Generat. Comput. Syst. 107, 841–853. https://doi.org/10.1016/j.future.2017.08.020.
Lin, W., Ortega, D.L., Ufer, D., Caputo, V., Awokuse, T., 2022. Blockchain-based traceability and demand for US beef in China. Appl. Econ. Perspect. Pol. 44 (1), 253–272. https://doi.org/10.1002/aepp.13135.
Liu, Z., Qian, Q., Hu, B., Shang, W.L., Li, L., Zhao, Y., Zhao, Z., Han, C., 2022. Government regulation to promote coordinated emission reduction among enterprises in the green supply chain based on evolutionary game analysis. Resour. Conserv. Recycl. 182, 106290 https://doi.org/10.1016/j.resconrec.2022.106290.
Lu, Y., 2019. The blockchain: state-of-the-art and research challenges. J. Ind. Inf. Integ. 15, 80–90. https://doi.org/10.1016/j.jii.2019.04.002.
Mutshewa, A., 2010. The use of information by environmental planners: a qualitative study using Grounded Theory methodology. Inf. Process. Manag. 46 (2), 212–232. https://doi.org/10.1016/j.ipm.2009.09.006.
Nakamoto, S., 2008. Bitcoin: A Peer-To-Peer Electronic Cash System. Decentralized Business Review.
Nayal, K., Raut, R.D., Narkhede, B.E., Priyadarshinee, P., Panchal, G.B., Gedam, V.V., 2021. Antecedents for blockchain technology-enabled sustainable agriculture supply chain. Ann. Oper. Res. 1–45 https://doi.org/10.1007/s10479-021-04423-3.
Nerín, C., Aznar, M., Carrizo, D., 2016. Food contamination during food process. Trends food Sci. Technolo. 48, 63–68. https://doi.org/10.1016/j.tifs.2015.12.004.
Niu, L., Chen, M., Chen, X., Wu, L., Tsai, F.S., 2021. Enterprise food fraud in China: key factors identification from social co-governance perspective. Front. Public Health 9, 752112. https://doi.org/10.3389/fpubh.2021.752112.
Osei, R.K., Canavari, M., Hingley, M., 2018. An Exploration into the Opportunities for Blockchain in the Fresh Produce Supply Chain. https://doi.org/10.20944/preprints201811.0537.v1.
Parks, P.C., 1992. AM Lyapunov's stability theory—100 years on. IMA J. Math. Control Inf. 9 (4), 275–303.
Peng, X., Zhang, X., Wang, X., Li, H., Xu, J., Zhao, Z., Wang, Y., 2022. Research on the cross-chain model of rice supply chain supervision based on parallel blockchain and smart contracts. Foods 11 (9), 1269. https://doi.org/10.3390/foods11091269.
Peter, A., 2017. In: China, You Can Track Your Chicken On–You Guessed It–The Blockchain. Fast Company, p. 82.
Priem, R.L., Li, S., Carr, J.C., 2012. Insights and new directions from demand-side approaches to technology innovation, entrepreneurship, and strategic management research. J. Manag. 38 (1), 346–374. https://doi.org/10.1177/0149206311429614.
Qin, K., Chen, X., Wu, L., 2022. The effects of psychological capital on citizens' willingness to participate in food safety social co-governance in China. Hum. Soc. Sci. Commun. 9 (1), 1–8. https://doi.org/10.1057/s41599-022-01302-5.
Ripolles-Avila, C., Hascoët, A.S., Martínez-Suárez, J.V., Capita, R., Rodríguez-Jerez, J.J., 2019. Evaluation of the microbiological contamination of food processing environments through implementing surface sensors in an iberian pork processing plant: an approach towards the control of Listeria monocytogenes. Food Control 99, 40–47. https://doi.org/10.1016/j.foodcont.2018.12.013.
Rodriguez-Salvador, B., Dopico, D.C., 2020. Understanding the value of traceability of fishery products from a consumer perspective. Food Control 112, 107142. https://doi.org/10.1016/j.foodcont.2020.107142.
Sanlier, N., 2009. The knowledge and practice of food safety by young and adult consumers. Food Control 20 (6), 538–542. https://doi.org/10.1016/j.foodcont.2008.08.006.
Seifermann, S., Murti, I.H., Oberle, J., 2022. Tracking and tracing in manufacturing supply chains using blockchain technology. Procedia CIRP 115, 172–177. https://doi.org/10.1016/j.procir.2022.10.069.
Tao, H., Hu, Y., Li, H., Fan, D., Chen, H., 2022. The credibility measurement model of food safety on-chain data based on blockchain. J. Internet Technol. 23 (4), 719–725. https://doi.org/10.53106/160792642022072304007.
Udeigwe, T.K., Teboh, J.M., Eze, P.N., Stietiya, M.H., Kumar, V., Hendrix, J., Mascagni Jr., H.J., Ying, T., Kandakji, T., 2015. Implications of leading crop production practices on environmental quality and human health. J. Environ. Manag. 151, 267–279. https://doi.org/10.1016/j.jenvman.2014.11.024.
Venkatesh, V.G., Kang, K., Wang, B., Zhong, R.Y., Zhang, A., 2020. System architecture for blockchain based transparency of supply chain social sustainability. Robot. Com-Integr. Manuf. 63, 101896 https://doi.org/10.1016/j.rcim.2019.101896.
Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Antonucci, F., Ioannoni, V., Fappiano, D., Costa, C., 2019. Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers? Foods 8 (11), 529. https://doi.org/10.3390/foods8110529.
Ward, D.R., Hart, K. (Eds.), 1996. HACCP: Hazard Analysis and Critical Control Point Training Curriculum. North Carolina Sea Grant.
Wong, L.W., Leong, L.Y., Hew, J.J., Tan, G.W.H., Ooi, K.B., 2020. Time to seize the digital evolution: adoption of blockchain in operations and supply chain management among Malaysian SMEs. Int. J. Inf. Manag. 52, 101997 https://doi.org/10.1016/j.ijinfomgt.2019.08.005.
World Health Organization, 1992. Hazard Analyss Critical Control Point. The document of WHO.
Wu, L., Liu, D., 2023. Internal mechanism and risk control of Chinese-style food safety governance system. Jiangsu Soc. Sci. 68–70, 05.
Wu, L., Lv, Y., Li, Q., Shan, L., 2017. Research progress of social Co-governance function in food safety risks. J. Dialectics Nat. 39, 142–152. https://doi.org/10.15994/j.1000-0763.2017.04.020, 04.
Wu, L., Xu, L., Wang, X., 2010. Main factors affecting consumers' willingness to pay additional prices for traceable foods and paying capacity - regression analysis based on logistic, interval censored. Chinese Rural Economy (4), 77–86.
Wu, J., Tran, N.K., 2018. Application of blockchain technology in sustainable energy systems: an overview. Sustainability 10 (9), 3067. https://doi.org/10.3390/su10093067.
Wu, L., Wang, S., Zhu, D., Hu, W., Wang, H., 2015. Chinese consumers' preferences and willingness to pay for traceable food quality and safety attributes: the case of pork. China Econ. Rev. 35, 121–136. https://doi.org/10.1016/j.chieco.2015.07.001.
Wu, X.Y., Fan, Z.P., Cao, B.B., 2023. An analysis of strategies for adopting blockchain technology in the fresh product supply chain. Int. J. Prod. Res. 61 (11), 3717–3734. https://doi.org/10.1080/00207543.2021.1894497.

Xu, X., Hu, H., Tan, Y., Yang, G., Zhu, P., Jiang, B., 2019. Quantifying the impacts of climate variability and human interventions on crop production and food security in the Yangtze River Basin, China, 1990–2015. Sci. Total Environ. 665, 379–389. https://doi.org/10.1016/j.scitotenv.2019.02.118.

Yu, Y., Zhou, Z., Jia, J., 2022. Threshold effect of government support on enterprise innovation performance and its regional differences. Transform. Bus. Econ. 21.

Zhang, Y., 2021. Research on Influence of Governmental Subsidy on Innovative Performance of Listed Companies in New-Energy Vehicle Industry. Zhejiang University. https://doi.org/10.27461/d.cnki.gzjdx.2021.001075.

Zhao, D., Tang, B., 2020. Multi-subject game of joint administration of food safety. J. South China Agricult. Univer.: Soci. Sci. Ed. 19, 80–92. https://doi.org/10.7671/j.issn.1672-0202.2020.05.008, 05.

Zhu, D., Tang, Y., Wu, L., 2023. Consumer preference for pork safety characteristics: considering rational and irrational behavior. Food Control 148, 109659. https://doi.org/10.1016/j.foodcont.2023.109659.