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An Evolutionary Game Model for Online Food Safety Governance Under Two Different Circumstances

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ABSTRACT Online food safety governance has received significant attention in recent years. In this research, a two-stage online food safety governance model, single governance mode (SGM), and co-governance mode (CGM) were constructed to explore governance performance. Results showed that under SGM, although the platforms could regulate enterprises' illegal behavior to a certain extent by increasing the discovery probability and increasing punishment, once the platforms relaxed supervision, enterprises' behavior would tend to choose the strategy of selling unsafe food. Therefore, the effect of platforms single governance was not ideal. Results also showed that the performance of CGM was not necessarily better than SGM. When the co-governance mode met the following two conditions, food enterprises in the online market would continue selling safe food: (1) the loss caused by government supervision to the illegal enterprises was greater than the difference between the cost of the enterprises to sell safe food and unsafe food; (2) the loss caused by the co-governance of the platforms and the government to the illegal enterprises was greater than the difference between the cost of the enterprises to sell safe food and unsafe food, meanwhile, the penalty imposed by the government on the passive platforms was greater than the supervision cost input of active platforms. The research revealed that the sufficient supply of safe food in the online market under CGM might depend significantly on the intensity of government supervision and the punishment of government to enterprises and platforms. Under CGM, compared with platform sectors, government supervision might play a more significant role in promoting food safety in the online market.

INDEX TERMS Online food safety, single governance mode, co-governance mode, evolutionary game.

I. INTRODUCTION

The deep integration of internet technology and the food industry has enabled more and more consumers to shift their food purchasing habits offline to online in recent years. Statistics showed that the Chinese online shopping market's transaction value reached 6.66 trillion RMB (approximately $940 billion) in 2019, with more than half of the sale consisting of food, beverage, and fresh products. Although buying food online enriched the offline shopping experience, consumers still paid great attention to online food safety issues. Data from a professional research institute in Beijing showed that among 140,000 public sentiment information of online food ordering service in 2018, nearly 40% of records related to online food safety issues [1], [2].

Compared with buying food in physical stores, online food transactions separated the information from food products. The only way for consumers to learn detailed food they want to buy was browsing the pictures and text information displayed on the online shopping platform [3]. Although the consumers could have a preliminary judgment on the food from its appearance, price, ingredient, production date, and shelf life, they might fail to understand the correct hygiene and quality of food sold online [4], [5]. Besides, the supply chain of online purchasing and offline distribution expanded in the online market, which was more likely to erupt food safety issues at the downstream process [6]. Thus, it was particularly important to pay more attention to the online food safety supervision process in the downstream sales link.

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However, due to the high complexity of the online food market, it is not easy to achieve adequate online food safety. Firstly, compared with traditional food safety supervision, the platform was introduced to the online food market as a new governance sector. This new subject's participation inevitably made traditional government-led food safety supervision more complicated [7]. In the context of the online food market, the platform was regarded as a regulator for food enterprise and considered an object regulated by the government [8]. Secondly, unlike ordinary products bought online, food was generally considered a unique commodity, which is more attributed to trust [9]. That is, the quality of food could not be determined through senses or consumption experiences. Due to the information asymmetry, consumers did not know whether the food they bought was harmful to health even after eating. Under the COVID-19 epidemic, consumers' demand for online food shopping has increased, and their safety issues are receiving constant attention. Therefore, it is essential to explore online food safety governance rules under the platform sectors' participation and learn their co-governance with government. To solve this problem, it is necessary to conduct a literature review of online food safety related research.

II. LITERATURE REVIEW

The current literature on online food safety mainly focused on two aspects. The first was the analysis of the legal framework of online food safety governance, and the second was the investigation of governance entities' behavior. Besides, this part will also review the application of evolutionary game theory in academic research.

A. LEGAL SYSTEM OF ONLINE FOOD SAFETY GOVERNANCE

As to the legal system of online food safety governance, there was no universal law for online food safety regulation, which meant the existing online food legal system failed to comprehensively cover all food categories [10]. Besides, online food safety laws did not differentiate regulatory bodies' authority and responsibility [11]. For example, the Chinese government had made efforts to introduce online food safety supervision into the 2015 *Food Safety Law*, as well as issued *Measures for the Investigation and Punishment of Online Food Safety Illegal Acts* in 2016, but it seemed that current regulation still could not solve problems such as the absence of governance subject, and unclear distribution of governance responsibility [12]. Hence, the lack of a legal system was considered a critical difficulty in online food safety governance.

B. MAIN GOVERNANCE SUBJECTS OF ONLINE FOOD MARKET

1) THE GOVERNMENT SECTOR

The government is an essential governing sector in both the traditional and online food market. Generally, the food market should not be intervened by the government sector if the market has a good trading order. However, government regulation should be highlighted if food supplied in the market failed to meet safety and quality levels [13]–[15]. Developed countries such as the USA, the UK, and Japan established responsible organizations for food safety under the government sector [16], [17]. Developing countries have also been continually improving their food safety governance institutions in recent years. As to China, since the melamine milk scandal in 2008, the food governance system has been continuously developed and improved [18]. After a long-term reform and reorganization of functional institutions, the Chinese government established a new food safety governance system [19]. In this new governance system, three administrative agencies were under the overall leadership of the National Food Safety Commission, which was the Ministry of Agriculture and Rural Affairs, State Administration of Market Supervision, and National Health and Safety Commission [20], [21]. Although the public sector institution was improved, it reflected that only relying on government cannot bring effective governance performance. Although the government showed a strong political will of enhancing food safety [22], [23], it might lag in policymaking, institution setting, and law enforcement when taking cost input into account [24], [25]. Therefore, the local government might focus on short-term benefits and neglect to take a long-term view of online food safety governance [26]–[29].

2) THE PLATFORM SECTOR

In the online food market, the enterprises' behavior was directly supervised by the platform sectors. The platforms were responsible for qualification review, information registration, and supervision during sales process [30]. Researchers pointed out that the third-party platform is an essential part of the food supply chain [31]. To provide a safe online food market, platforms were expected to improve their signal detection mechanism [32]. However, only with platforms' single governance would also cause harmful effects. When the platforms were the only governance body in the market, the platforms might be driven by interests to over-expand the scale, unilaterally emphasized their supervision effects, and exaggerated the power [33]. These behaviors could lead to incomplete regulation of illegal enterprises and caused failures to form a joint regulatory force with the government [34], [35].

Therefore, it was found that one-sided emphasis on single supervision of the government or the platforms might not achieve the effective performance of online food safety governance [36]–[38]. In recent years, with the co-governance concept being put forward, some scholars believed that the co-operation between the public and the private sectors could improve food safety regulation [39]–[42]. In online food environment, platforms were regarded as new governance subjects. Whether the co-governance mode of platforms and the government can fully improve online food safety is worth discussing.

C. THE APPLICATION OF EVOLUTIONARY GAME THEORY

Evolutionary game theory was first introduced to analyze behaviors among biological groups. The development of the theory was gradually used to explore the behavioral strategy selection between different groups in a specific environment to help different groups make optimal strategic choices [43]. The review of relevant literature found that this theory was widely used to discuss general social issues with multiple stakeholders' participation [44]. For example, Wang and Shi [45] constructed an evolutionary game model between government and enterprise under the static and dynamic punishment mechanism to explore a better way to deal with industrial pollution control [45]. Han *et al.* [46] constructed an evolutionary game model between the government and the private sector under a PPP project to study whether the engineering project construction can better achieve fairness [46]. Pu *et al.* [47] built an evolutionary game model, including the ride-hailing platform, passenger, and driver, to determine the benign regulation of the ride-hailing service [47]. Liu and Wang [48] constructed an evolutionary game model between food enterprise and cold chain logistics enterprises in fresh food delivery to provide a safe cold chain provision [48].

At present, few studies used the evolutionary game theory to study online food safety governance issues. However, some studies used this method to discuss governance issues in the Internet shopping environment. For example, He and Zhu [49] focused on the collusion behavior between online companies and platforms. Researchers found that enhancing the loss-sharing relationship between the online seller and the e-commerce platform can prevent collusion behavior [49]. Li *et al.* [50] built a supervision game model between the governmental quality supervision department and the online shopping platform. It was found that the supervision performance of government and platforms was affected by the supervision cost [50]. However, we also found some limitations to these studies. Firstly, in the study of He and Zhu [50], although researchers regarded the platform as one important participant, they did not give the platform sectors the supervision power and only divided the platforms' behavioral strategy selection into two strategies: colluding with enterprises or not colluding with enterprises [49]. This was different from the reality that the platform was directly responsible for managing the settled enterprises [33]. Secondly, although the government supervision was introduced into research studies, these studies assumed that when the government implemented supervision, it could discover the enterprises' illegal behavior, which was not consistent with reality [49], [50]. In reality, even if the government earnestly fulfilled its regulatory duties, some illegal enterprises and platforms would inevitably be missed due to the limitation of government's regulatory resource.

From these above researches, it was found that current evolutionary game model construction of the online shopping market was more concerned with the government supervision of platforms' and enterprises' behavior while ignoring the supervision between the platforms' governance on enterprises. Besides, it was not certain that the governing bodies could find the market's unsafe factors as long as they implemented supervision. Based on this, we believed that regulatory bodies of online market, the government and the platform, had regulatory probability when they implement supervision. The introduction of this probability made this research more in line with the reality of online shopping market governance. In addition, existing research on quality supervision of online shopping focused mainly on general commodities and seldom involved online food. Due to the special nature of food, platforms and governments should pay more attention to online food safety governance. Considering most current research on online food safety governance was at the theoretical level and lacked the model analysis based on real situation, this study explored a two-stage evolutionary game model for online food safety governance that aimed to find out factors that could affect the performance of online food safety governance. To be specific, the first was the single governance mode (SGM) when only the platforms govern the settled enterprises, while the second was the co-governance mode (CGM) when the platforms and the government jointly participate in the governance.

This research has given the evolutionary game model a new application scenario by constructing a two-stage online food safety governance mode. During this process, the platform sectors' supervisory power was given, and the discovery probability of supervisory entities was introduced. By doing so, it made model construction more in line with actual governance circumstances. The inspection of governance effect on SGM and CGM can provide some theoretical and technical basis for online food safety governance.

III. THE EVOLUTIONARY GAME MODEL OF ONLINE FOOD SAFETY UNDER THE SGM

In this section, an evolutionary game model of single governance mode (SGM) is presented and described in detail.

A. RESEARCH ASSUMPTIONS

Assumption 1: There are two main sectors in the process of online food safety governance. The first sectors are considered as the online platforms, marked as (OP). And the second sectors are considered as the platform enterprises, marked as (PE). Besides, we suppose that both the online platforms and the enterprises are bounded rational stakeholders aiming to achieve maximum utility. Considering it is difficult for each player to find the optimal strategy in the initial stage, we assume that each player will adjust its strategy by observing participants' strategy choices with higher market returns.

Assumption 2: In this assumption, we need to define the strategy set of both players. To illustrate, we assume that each stakeholder is supposed to contain two opposing evolutionary strategies. In online food market sales governance, the platforms can directly supervise the food selling enterprises. According to the degree of supervision, the platforms can choose two strategies: active supervision and passive supervision. As for the food selling safety, the platform enterprises strategic choices are: selling safe food and selling unsafe food.

Assumption 3: We suppose that the probability concerning the platforms' active supervision of the enterprises is x, and that of its passive supervision is $1-x$. Moreover, the probability that the settled enterprises sell safe food is y, and that of selling unsafe food is $1-y$. It is obvious that $x, y \in [0, 1]$, $1-x, 1-y \in [0, 1]$.

B. PARAMETERS SETTING

We assume that the platform enterprises will pay a different cost considering the willingness to sell safe food or not. We suppose that the cost inputs of choosing to sell safe food and unsafe food for enterprises are c_H and c_L, respectively. It is obvious that $c_H > c_L > 0$. In the process of selling food online, the enterprises can obtain a stable income, which can be recorded as b. In addition, the settled enterprises need to pay a total expense of E to the platforms, including service and advertising fees. As to the platforms, we assume that the investment in the active and passive regulatory strategies is recorded as c_P and 0 respectively. During the implementation of active supervision, the platform has the probability of α to find out the illegal behaviors of the enterprises and punish them with F_1. In this case, we call the governance mode the SGM. Based on the above SGM assumptions, the main parameters are shown in Table 1. Additionally, the payoff matrix of the online platforms and the platform enterprises is constructed, as shown in Table 2.

TABLE 1. Description of main parameters.

Symbol	Definition	Value Range
OP	The online platform	-
PE	The platform enterprise	-
x	Probability of platforms with active supervision	$0 \le x \le 1$
y	Probability of enterprises to sell safe food	$0 \le y \le 1$
c_H	Cost input for enterprises to sell safe food	$c_H > 0$
c_L	Cost input for enterprises to sell unsafe food	$c_L > 0$
c_P	Cost input for platforms with active supervision	$c_P > 0$
b	The income of enterprises to sell food online	$b > 0$
E	Expenses charged by the platforms from enterprises	$E > 0$
α	Probability of selling unsafe food found by platforms	$0 \le \alpha \le 1$
F_1	Penalty imposed by platforms on enterprises of selling unsafe food	$F_1 > 0$

TABLE 2. The payoff matrix of the platform and enterprise under SGM.

The Platform Enterprise	The Online Platform	
	Active supervision (x)	Passive supervision ($1-x$)
Sell safe food (y)	$b-c_H-E$, $E-c_P$	$b-c_H-E$, E
Sell unsafe food ($1-y$)	$b-c_L-E-\alpha F_1$, $E-c_P+\alpha F_1$	$b-c_L-E$, E

C. THE EVOLUTIONARY GAME BETWEEN PLATFORMS AND ENTERPRISES

In this section, the evolutionary game for online food safety under the SGM is established. From the analysis of the game model matrix, the expected return of the platforms that choose the active supervision strategy is

$$\mu_{11} = y(E - c_P) + (1-y)(E - c_P + \alpha F_1) \tag{1}$$

The expected return of selecting the passive supervision strategy is

$$\mu_{12} = yE + (1-y)E \tag{2}$$

The average expected return of the platforms is

$$\mu_1 = x\mu_{11} + (1-x)\mu_{12} \tag{3}$$

Then, according to Equations (1)-(3), the replicated dynamic equation of the platforms' selection for active supervision can be obtained as follows

$$OP(x) = \frac{dx}{dt} = x(\mu_{11} - \mu_1) = x(1-x)[-y\alpha F_1 + \alpha F_1 - c_P] \tag{4}$$

Similarly, the expected return of the platform enterprises that choose to sell safe food is

$$\mu_{21} = x(b - c_H - E) + (1-x)(b - c_H - E) \tag{5}$$

The expected return of choosing to sell unsafe food is

$$\mu_{22} = x(b - c_L - E - \alpha F_1) + (1-x)(b - c_L - E) \tag{6}$$

The average expected return of the platform enterprises is

$$\mu_2 = y\mu_{21} + (1-y)\mu_{22} \tag{7}$$

Furthermore, from Equations (5)–(7), we obtain the replicated dynamic equation of the platform enterprises' choice for safe food sales as follows

$$PE(y) = \frac{dy}{dt} = y(\mu_{21} - \mu_2) = y(1-y)[x\alpha F_1 - (c_H - c_L)] \tag{8}$$

Thus, according to Equations (4) and (8), a dynamic system (9) is given by

$$\begin{cases} OP(x) = \dfrac{dx}{dt} = x(\mu_{11} - \mu_1) = x(1-x)[-y\alpha F_1 + \alpha F_1 - c_P] \\ PE(y) = \dfrac{dy}{dt} = y(\mu_{21} - \mu_2) = y(1-y)[x\alpha F_1 - (c_H - c_L)] \end{cases} \tag{9}$$

1) THE JACOBIAN MATRIX PARTIAL STABILITY ANALYSIS

Let $OP(x) = 0$ and $PE(y) = 0$, then the five local equilibrium points of the system evolution, namely (0,0), (0,1), (1,0), (1,1) and (x^*, y^*) can be obtained. In this case, $x^* = \frac{c_H - c_L}{\alpha F_1}$, $y^* = \frac{\alpha F_1 - c_P}{\alpha F_1}$. The local stability of the Jacobian matrix can be used to determine the stability of the equilibrium point. From dynamic system (9), we can get the Jacobian matrix as follows:

$$J=\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} (1-2x)(-y\alpha F_1+\alpha F_1-c_P) & x(1-x)(-\alpha F_1) \\ y(1-y)(\alpha F_1) & (1-2y)(x\alpha F_1 - c_H+c_L) \end{bmatrix} \tag{10}$$

When $det\,|J| = a_{11}a_{22} - a_{12}a_{21} > 0$ and $tr\,|J| = a_{11} + a_{22} < 0$ are satisfied at the same time, the local equilibrium point of the system is the evolutionarily stable equilibrium point. At this time, the value at the local equilibrium point of the system is shown in Table 3.

TABLE 3. Values at the local equilibrium point of the system.

Equilibrium Point		Expression
(0,0)	$det\|J\|$	$(\alpha F_1-c_P)(c_L-c_H)$
	$tr\|J\|$	$(\alpha F_1-c_P)+(c_L-c_H)$
(0,1)	$det\|J\|$	$-c_P(c_H-c_L)$
	$tr\|J\|$	$-c_P+(c_H-c_L)$
(1,0)	$det\|J\|$	$-(\alpha F_1-c_P)[\alpha F_1-(c_H-c_L)]$
	$tr\|J\|$	$-(\alpha F_1-c_P)+[\alpha F_1-(c_H-c_L)]$
(1,1)	$det\|J\|$	$c_P[(c_H-c_L)-\alpha F_1]$
	$tr\|J\|$	$c_P+[(c_H-c_L)-\alpha F_1]$
(x^*, y^*)	$det\|J\|$	$\frac{(c_H-c_L)[\alpha F_1-(c_H-c_L)](\alpha F_1-c_P)c_P}{(\alpha F_1)^2}$
	$tr\|J\|$	0

As at point (x^*, y^*), $a_{11} + a_{22} = 0$, which fails to satisfy $tr\,|J| < 0$. Hence, point (x^*, y^*) is not an evolutionarily stable equilibrium point, and the other four local equilibrium points should also be judged. From parameters setting above, we can see that $c_H - c_L > 0$. Furthermore, the following four cases are discussed.

Case 1. When $\alpha F_1 - c_P < 0$ and $\alpha F_1 - (c_H - c_L) > 0$, the system evolutionary stability of local equilibrium point is shown in Table 4.

TABLE 4. System evolutionary stability analysis in Case 1.

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	+	-	ESS
(0,1)	-	Uncertain	Saddle point
(1,0)	+	+	Unstable point
(1,1)	-	Uncertain	Saddle point

Case 2. When $\alpha F_1 - c_P < 0$ and $\alpha F_1 - (c_H - c_L) < 0$, the system evolutionary stability of local equilibrium point is shown in Table 5.

TABLE 5. System evolutionary stability analysis in Case 2.

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	+	-	ESS
(0,1)	-	Uncertain	Saddle point
(1,0)	-	Uncertain	Saddle point
(1,1)	+	+	Unstable point

As shown in Cases 1 and 2, when the punishment imposed by the platforms on illegal enterprises is less than the platforms' input of active supervision, no matter the punishment of the platforms is greater than or less than the difference between the cost of selling safe food and unsafe food, the evolutionary stable strategy (ESS) of the system is (0,0). The corresponding strategy combination is (passive supervision, sell unsafe food).

MATLAB is used as a tool for numerical simulation. In this paper, we assign some basic parameters according to the actual situation of China's online food market. Take Meituan, the largest take-out platform in the Chinese market as an example. When consumers buy food online, the platform usually has a setting starting from 20 RMB for a single order. In this study, we assume that the average amount of each order is about 25 RMB. At the same time, the platform will charge commission for each order sold by enterprise, which accounts for 20% of the enterprise income. In other words, the fee charged by the platform for enterprises is assumed to be 5 yuan. In addition, the parameters should meet the requirement that the cost input when the platform is actively supervised less than the fees paid by enterprises to the platform. The punishment imposed by the platform on illegal enterprises should be greater than the cost input of selling unsafe food. Hence, assuming $b = 25$, $E = 5$, $c_H = 8$, $c_L = 5$, $c_P = 5$, $\alpha = 0.6$, $F_1 = 6$ satisfy case 1, while $b = 25$, $E = 5$, $c_H = 8$, $c_L = 5$, $c_P = 5$, $\alpha = 0.3$, $F_1 = 6$ meet case 2. In order to entirely present the evolutionary game between the online platforms and the enterprises, four initial states of (x_0, y_0) were simulated with different probabilities. We assume that the initial probability of the platforms choosing the active supervision strategy and that of the settled enterprises adopting the safe food marketing strategy are denoted as x_0 and y_0. (0.2, 0.8), (0.2, 0.2), (0.8, 0.2), (0.8, 0.8) are the four initial states refer to four different strategies selected by the online platforms and the enterprises. We assume that when the initial value comes to 0.8 level, it refers to a strong willingness for the platforms' active supervision or the enterprises to sell safe food. When it comes to 0.2 level, it means that a weak willingness for platforms' active supervision or the enterprises to sell safe food.

The simulation analysis is presented in Figure 1 and Figure 2 below. From the presented figures, it is found that the choices of evolutionary behavior strategy for both sides of the game gradually approach 0 from the initial value. The corresponding strategy combination is passive supervision for the platforms and selling unsafe food for the enterprises.

Case 3. When $\alpha F_1 - c_P > 0$ and $\alpha F_1 - (c_H - c_L) > 0$, there is no evolutionarily stable strategy of local equilibrium

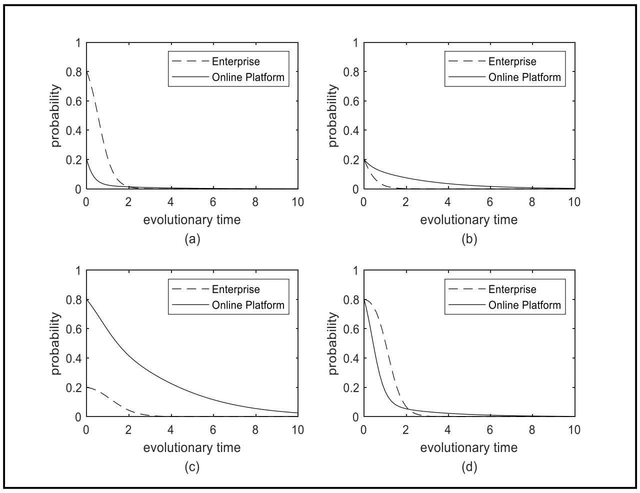

FIGURE 1. **Simulation results of evolutionary stability point in Case 1. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

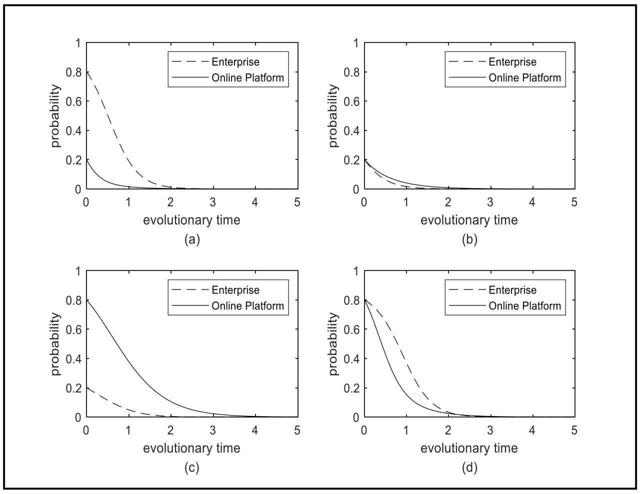

FIGURE 2. **Simulation results of evolutionary stability point in Case 2. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

TABLE 6. **System evolutionary stability analysis in Case 3.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	-	Uncertain	Saddle point
(0,1)	-	Uncertain	Saddle point
(1,0)	-	Uncertain	Saddle point
(1,1)	-	Uncertain	Saddle point

point. The analysis on system evolutionary stability is shown in Table 6.

As shown in Case 3, when the parameters meet: (1) the punishment imposed by the platforms on illegal enterprises is greater than the platforms' input of active supervision; (2) the punishment imposed by the platforms on illegal enterprises is greater than the difference between the cost of selling

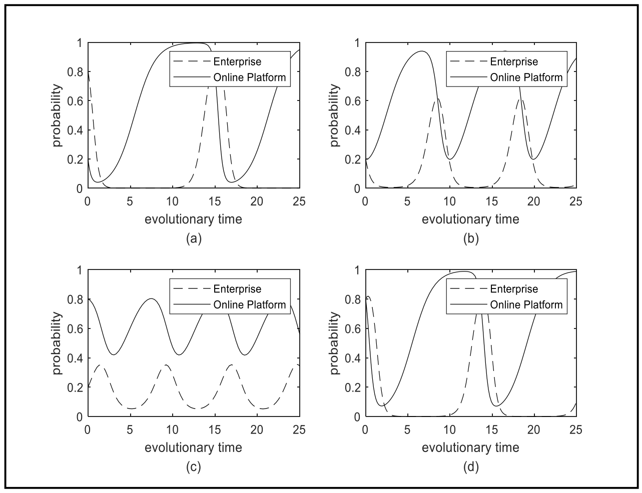

FIGURE 3. **Simulation results of evolutionary stability point in Case 3. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

safe food and unsafe food, there is no evolutionary stability strategy (ESS) in the system. No certain strategy between the platforms and the enterprises is reached.

Assuming $b = 25$, $E = 5$, $c_H = 8$, $c_L = 5$, $c_P = 5$, $\alpha = 0.7$, and $F_1 = 9$. The simulation analysis is presented in Figure 3. It can be found that no matter what the initial state is, the strategy between the platforms and the enterprises is uncertain. The behavior strategy choice of the both sides in the game is in a state of periodic oscillation from the initial value, and the online food safety is featured with a motion-type governance model. Despite both the platforms and the enterprises show a periodic oscillation trend, it reflects that the behavior of enterprises lags to a certain extent than platforms' behavior.

Case 4. When $\alpha F_1 - c_P > 0$ and $\alpha F_1 - (c_H - c_L) < 0$, the system evolutionary stability of local equilibrium point is shown in Table 7.

TABLE 7. **System evolutionary stability analysis in Case 4.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	-	Uncertain	Saddle point
(0,1)	-	Uncertain	Saddle point
(1,0)	+	-	ESS
(1,1)	+	+	Unstable point

As shown in Case 4, when the parameters meet: (1) the punishment imposed by the platforms on illegal enterprises is greater than the platforms' input of active supervision; (2) the punishment imposed by the platforms on illegal enterprises is less than the difference between the cost of selling safe food and unsafe food, the evolutionary stable strategy (ESS) of the system is (1,0). The corresponding strategy combination is (active supervision, sell unsafe food). This time, although the governance subject carries out the standard supervision action, the strategy choice of the enterprises fails to enhance the quality and safety of the online food market.

Assuming $b = 25$, $E = 5$, $c_H = 8$, $c_L = 3$, $c_P = 3$, $\alpha = 0.7$, and $F_1 = 7$. The simulation analysis is presented in Figure 4. It is found that the selection of platforms' evolutionary behavior strategy gradually approaches 1 from the initial value, while that of enterprises evolution behavior strategy is gradually close to 0 from the initial value. The evolutionary stable strategy of the system is (1,0). The corresponding strategy combination is active supervision for the platforms and selling unsafe food for the enterprises.

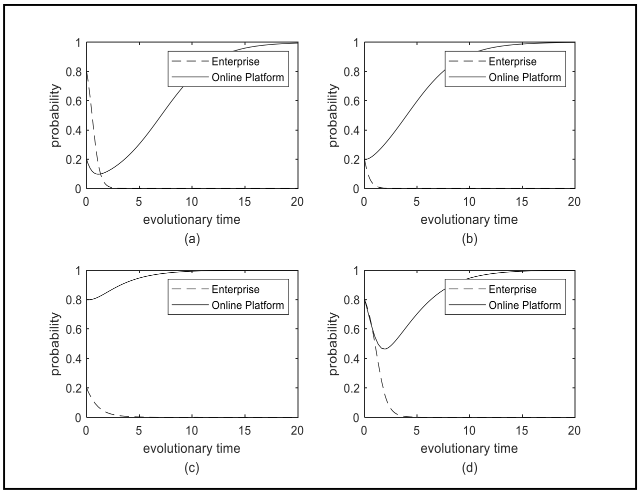

FIGURE 4. Simulation results of evolutionary stability point in Case 4. (a) $x_0 = 0.2, y_0 = 0.8$; (b) $x_0 = 0.8, y_0 = 0.2$; (d) $x_0 = 0.8, y_0 = 0.8$.

To sum up, under the SGM where only the online platforms were the governance subject, there are three possible outcomes for the evolution and stable equilibrium of the strategies for both sides of the game in the online food market, namely (0,0), (1,0) and non-existence. These results are manifested that as in the SGM online food market, the continuous and effective supply of qualified food cannot be guaranteed. We found that enterprises' behavior is affected by the degree of platforms supervision. When the punishment for the illegal enterprises is greater than the difference between the cost of selling safe and unsafe food; and the punishment for the illegal enterprises is greater than the cost input of the active supervision of the platforms, the behavior of the food enterprises will be switch back and forth between two strategic options in the sale of safe and unsafe food. Therefore, by increasing the platform discovery probability and platform penalty, SGM's food safety governance effect can be improved. However, SGM cannot make the enterprises' behavioral strategy stable to sell safe food. There could be several underlying reasons for this. For one thing, the lack of external constraints makes the platform lack of self-regulatory motivation. It is the fact that the revenue of the platform mainly comes from various fees paid by the settled enterprises. In order to maximize their own interests, the platform will relax supervision on illegal behavior of enterprise. As for the enterprises, when the supervision of the platform has posed no threat to their illegal behaviors, more illegal enterprises will be attracted to join in the online market. In this case, food quality and safety problems are out of control.

IV. THE EVOLUTIONARY GAME MODEL OF ONLINE FOOD SAFETY UNDER THE CGM

Through the analysis on the game model of online food safety evolution under the single governance mode (SGM), it is shown that the order of the online food market cannot be effectively regulated simply by relying on the platform supervision. Inspired by the co-governance concerning multiple subjects of traditional food safety, this section introduces the government participation in SGM based on the actual situation of online food market governance, thereby constructing a co-governance mode (CGM), which can further investigate the evolution equilibrium of online food safety under the co-governance of the platform and the government. Besides, it should be noticed that this co-governance mode is closer to the reality and completes the real situation to a large extent. Based on the SGM, an evolutionary game model of CGM is presented and described in detail.

A. RESEARCH ASSUMPTIONS

Assumption 4: We suppose that the government has the right to supervise both the negative supervised platforms and illegal enterprises. We assume that the government agency, as a public authority, can perform its supervisory duties, and the order of government supervision over the enterprises is after the platform supervision over the enterprises.

Assumption 5: Besides, it is also supposed that the government's supervision will not affect the platforms' existing regulatory intensity and punishment for the settled enterprises.

B. PARAMETERS SETTING

Based on SGM, several parameters are further assumed in CGM. When the enterprises' illegal behavior is found, the government will not only impose a fine, but also order it to suspend business within a certain period of time for rectification, thus resulting in the profit loss of the enterprises, which we defined it as L. Government will also supervise the behavior of the platforms. It is supposed that the probability of the government's investigation and punishing illegal enterprises is p and the fine is F_2, while the probability of the government's investigation and punishing passive supervision platforms is q, and the penalty is F_3. Based on the above CGM assumptions, newly added parameters are shown in Table 9. Additionally, the payoff matrix of the platforms and the enterprises in CGM is constructed in Table 10.

C. THE EVOLUTIONARY GAME BETWEEN PLATFORM AND ENTERPRISE UNDER THE CGM

According to the analysis of the game model matrix, after the introduction of government participation in governance, the expected return of the platforms that choose the active

TABLE 8. Newly added parameter description.

Symbol	Definition	Value Range
p	Probability of selling unsafe food found by the government	$0 \le p \le 1$
F_2	Penalty imposed by the government on enterprises of selling unsafe food	$F_2 > 0$
q	Probability of the platform passive supervision found by the government	$0 \le q \le 1$
F_3	Penalty imposed by the government on platforms of passive supervision	$F_3 > 0$
L	Income loss of the enterprises during rectification periods	$L > 0$

TABLE 9. The payoff matrix of the platform and enterprise under CGM.

The Platform Enterprise	The Online Platform	
	Active supervision (x)	Passive supervision ($1-x$)
Sell safe food (y)	$b-c_H-E$, $E-c_P$	$b-c_H-E$, $E-qF_3$
Sell unsafe food ($1-y$)	$b-c_L-E-\alpha F_1-pF_2-pL$, $E-c_P+\alpha F_1$	$b-c_L-E-pF_2-pL$, $E-qF_3$

TABLE 10. Values at the local equilibrium point of the system.

Equilibrium Point		Expression
(0,0)	$det\|J\|$	$(\alpha F_1+qF_3-c_P)[(pF_2+pL)-(c_H-c_L)]$
	$tr\|J\|$	$(\alpha F_1+qF_3-c_P)+[(pF_2+pL)-(c_H-c_L)]$
(0,1)	$det\|J\|$	$(qF_3-c_P)[(c_H-c_L)-(pF_2+pL)]$
	$tr\|J\|$	$(qF_3-c_P)+[(c_H-c_L)-(pF_2+pL)]$
(1,0)	$det\|J\|$	$[c_P-(\alpha F_1+qF_3)][(\alpha F_1+pF_2+pL)-(c_H-c_L)]$
	$tr\|J\|$	$[c_P-(\alpha F_1+qF_3)]+[(\alpha F_1+pF_2+pL)-(c_H-c_L)]$
(1,1)	$det\|J\|$	$(c_P-qF_3)[(c_H-c_L)-(\alpha F_1+pF_2+pL)]$
	$tr\|J\|$	$(c_P-qF_3)+[(c_H-c_L)-(\alpha F_1+pF_2+pL)]$
(x^*, y^*)	$det\|J\|$	$\frac{(c_H-c_L-pF_2-pL)[(\alpha F_1+pF_2+pL)-(c_H-c_L)](\alpha F_1+qF_3-c_P)(c_P-qF_3)}{(\alpha F_1)^2}$
	$tr\|J\|$	0

supervision strategy is

$$\mu'_{11} = (1-y)\alpha F_1 + E - c_P \tag{11}$$

The expected return of choosing the passive regulatory strategy is

$$\mu'_{12} = E - qF_3 \tag{12}$$

The average expected return of the platforms is

$$\mu'_1 = x\mu'_{11} + (1-x)\mu'_{12} \tag{13}$$

Then, according to Equations (11)-(13), the replicated dynamic equation $OP(x)$ of the platforms' selection for active supervision can be obtained as follows

$$OP(x) = \frac{dx}{dt} = x(1-x)(-y\alpha F_1+\alpha F_1+qF_3-c_P) \tag{14}$$

Similarly, after the introduction of government participation governance, the expected return of the settled enterprises who choose to sell safe food is

$$\mu'_{21} = b - c_H - E \tag{15}$$

The expected return of choosing to sell unsafe food is

$$\mu'_{22} = b - c_L - E - pF_2 - pL - x\alpha F_1 \tag{16}$$

The average expected return of the settled enterprises is

$$\mu'_2 = y\mu'_{21} + (1-y)\mu'_{22} \tag{17}$$

Furthermore, from Equations (15)-(17), we obtain the replicated dynamic equation $PE(y)$ of the enterprises' choice for safe food sales as follows

$$PE(y)=\frac{dy}{dt}=y(1-y)[x\alpha F_1+pF_2+pL-(c_H-c_L)] \tag{18}$$

Thus, according to Equations (14) and (18), a dynamic system (19) is given by

$$\begin{cases} OP(x) = \dfrac{dx}{dt} = x(1-x)(-y\alpha F_1+\alpha F_1+qF_3-c_P) \\ PE(y) = \dfrac{dy}{dt} = y(1-y)[x\alpha F_1+pF_2+pL-(c_H-c_L)] \end{cases} \tag{19}$$

Let $OP(x) = 0$ and $PE(y) = 0$, and then the five local equilibrium points namely (0,0), (0,1), (1,0), (1,1) and (x^*, y^*) of the system evolution can be obtained. In this case, $x^* = \frac{c_H-c_L-pF_2-pL}{\alpha F_1}$, $y^* = \frac{\alpha F_1+qF_3-c_P}{\alpha F_1}$. From dynamic system (19), we can get the Jacobian matrix as (20), shown at the bottom of the page.

At this time, the value at the local equilibrium point of the system is shown in Table 11.

By taking the local equilibrium point as the judgment condition of the evolutionary stability strategy and combining with the participation constraints mentioned above, whether the local equilibrium points are the evolutionary stable equilibrium points is judged. At point (x^*, y^*), $a_{11} + a_{22} = 0$, which fails to satisfy the condition of $tr\,|J| < 0$. Thus, point (x^*, y^*) is not an evolutionary stable equilibrium point, and the other four local equilibrium points should also be judged. Furthermore, the following cases are discussed.

Case 5. When $(pF_2+pL)-(c_H-c_L) > 0$, and $qF_3-c_P > 0$, the system evolutionary stability of local equilibrium point is shown in Table 11.

$$J = \begin{bmatrix} (1-2x)(-y\alpha F_1+\alpha F_1+qF_3-c_P) & x(1-x)(-\alpha F_1) \\ y(1-y)\alpha F_1 & (1-2y)(x\alpha F_1+pF_2+pL-c_H+c_L) \end{bmatrix} \tag{20}$$

TABLE 11. System evolutionary stability analysis in Case 5.

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	+	+	Unstable point
(0,1)	-	Uncertain	Saddle point
(1,0)	-	Uncertain	Saddle point
(1,1)	+	-	ESS

As shown in Case 5, when the parameters meet: (1) the sum of the fines undertaken by illegal enterprises who are investigated by the government and the income loss of rectification is greater than the difference between the cost of selling safe food and unsafe food; (2) the punishment imposed by the government on passive platforms is greater than the platforms' supervision input, the evolutionary stable strategy (ESS) of the system is (1,1).

Assuming $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.6, p = 0.4, q = 0.7, F_1 = 6, F_2 = 7, F_3 = 8$, and $L = 3$. The simulation results of evolutionary stability in case 5 is shown in Figure 5. From the presented figure, it can be found that the game evolutionary behavior strategy selection of both sides gradually approaches 1 from the initial value. The corresponding strategy combination is active supervision for the platforms and selling safe food for the enterprises.

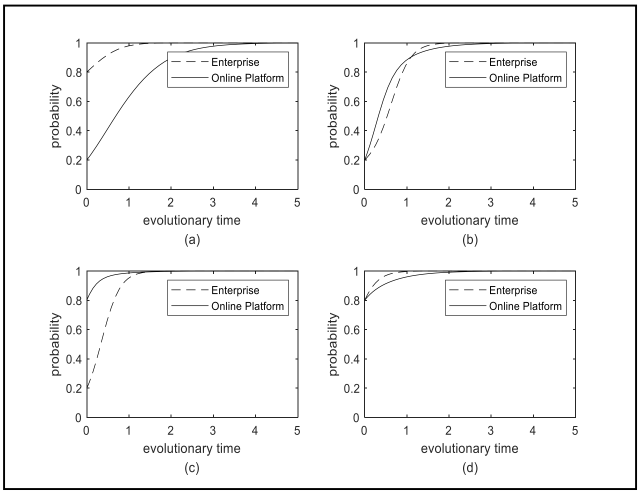

FIGURE 5. Simulation results of evolutionary stability point in Case 5. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.

Case 6. When $(pF_2 + pL) - (c_H - c_L) > 0, qF_3 - c_P < 0$, and $\alpha F_1 + qF_3 - c_P > 0$, the system evolutionary stability of local equilibrium point is shown in Table 12.

Case 7. When $(pF_2 + pL) - (c_H - c_L) > 0, qF_3 - c_P < 0$, and $\alpha F_1 + qF_3 - c_P < 0$, the system evolutionary stability of local equilibrium point is shown in Table 13.

As shown in Case 6 and Case 7, when the parameters meet: (1) the sum of the fines undertaken by illegal enterprises who are investigated by the government and the income loss of rectification is greater than the difference between the cost of selling safe food and unsafe food; (2) the punishment imposed by the government on passive platforms is less than the platforms' supervision input, the evolutionary stable strategy (ESS) of the system is (0,1).

TABLE 12. System evolutionary stability analysis in Case 6.

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	+	+	Unstable point
(0,1)	+	-	ESS
(1,0)	-	Uncertain	Saddle point
(1,1)	-	Uncertain	Saddle point

TABLE 13. System evolutionary stability analysis in Case 7.

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	-	Uncertain	Saddle point
(0,1)	+	-	ESS
(1,0)	+	+	Unstable point
(1,1)	-	Uncertain	Saddle point

Assuming $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.6, p = 0.4, q = 0.4, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$ satisfy case 6; while $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.2, p = 0.4, q = 0.4, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$ meet case 7. The simulation results of evolutionary stability in case 6 and case 7 are shown in Figure 6 and Figure 7. From the presented figures, it can be found that the choice of platforms' behavior strategy has gradually moved towards 0 until reaching stability. And the behavior strategy of settled enterprises has gradually moved towards 1. The corresponding strategy combination is passive supervision for the platforms and selling safe food for the enterprises.

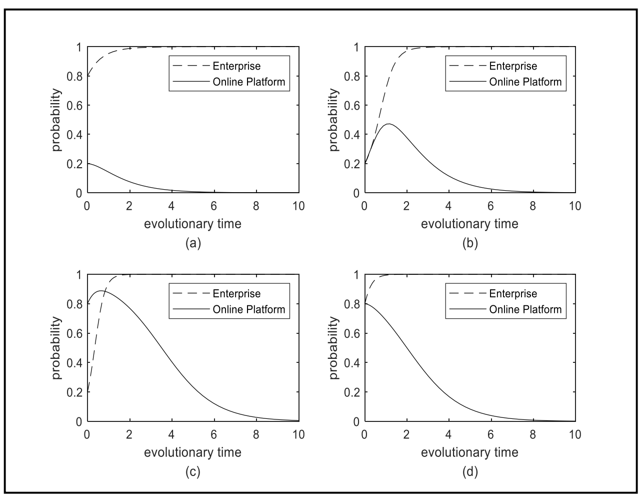

FIGURE 6. Simulation results of evolutionary stability point in Case 6. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.

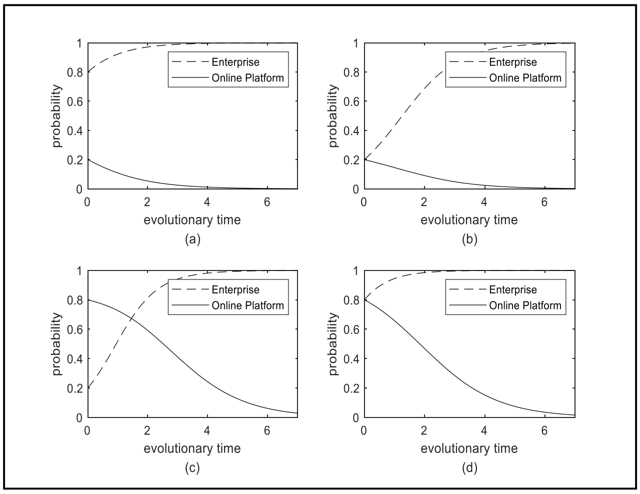

FIGURE 7. **Simulation results of evolutionary stability point in Case 7. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

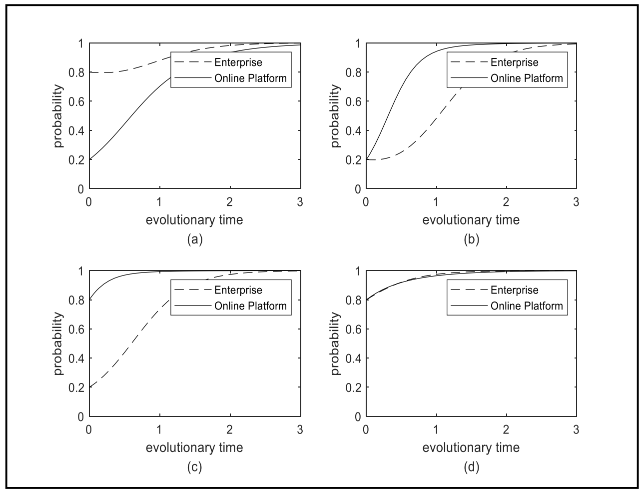

FIGURE 8. **Simulation results of evolutionary stability point in Case 8. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

TABLE 14. **System evolutionary stability analysis in Case 8.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	-	Uncertain	Saddle point
(0,1)	+	+	Unstable point
(1,0)	-	Uncertain	Saddle point
(1,1)	+	-	ESS

TABLE 15. **System evolutionary stability analysis in Case 9.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	-	Uncertain	Saddle point
(0,1)	+	+	Unstable point
(1,0)	+	-	ESS
(1,1)	-	Uncertain	Saddle point

Case 8. When $(pF_2 + pL) - (c_H - c_L) < 0$, $(\alpha F_1 + pF_2 + pL) - (c_H - c_L) > 0$, and $qF_3 - c_P > 0$, the system evolutionary stability of local equilibrium point is shown in Table 14.

As shown in Case 8, when the parameters meet: (1) the sum of the fines undertaken by illegal enterprises who are investigated by the government and the income loss of rectification is less than the difference between the cost of selling safe food and unsafe food; (2) the sum of the fines undertaken by illegal enterprises who are investigated by both platform and government, as well as the income loss of rectification is greater than the difference between the cost of selling safe food and unsafe food; (3) the punishment imposed by the government on passive platform is greater than the platform's active supervision input, the evolutionary stable strategy (ESS) of the system is (1,1).

Assuming $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.6, p = 0.2, q = 0.7, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$. The simulation results of evolutionary stability in case 8 is shown in Figure 8. From the presented figure, it can be found that the game evolutionary behavior strategy selection of both sides gradually approaches 1 from the initial value. The corresponding strategy combination is active supervision for the platforms and selling safe food for the enterprises.

Case 9. When $(pF_2 + pL) - (c_H - c_L) < 0$, $(\alpha F_1 + pF_2 + pL) - (c_H - c_L) < 0$, and $qF_3 - c_P > 0$, the system evolutionary stability of local equilibrium point is shown in Table 15.

As shown in Case 9, when the parameters meet: (1) the sum of the fines undertaken by illegal enterprises who are investigated by both platforms and government, as well as the income loss of rectification is less than the difference between the cost of selling safe food and unsafe food; (2) the punishment imposed by the government on passive platforms is greater than the platforms' supervision input, the evolutionary stable strategy (ESS) of the system is (1,0).

Assuming $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.1, p = 0.2, q = 0.7, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$. The simulation results of evolutionary stability in case 9 is shown in Figure 9. From the presented figures, it can be found that the choice of platforms behavior strategy has gradually moved towards 1 until reaching stability. And the behavior strategy of settled enterprises has gradually moved towards 0. The corresponding strategy combination is active supervision for the platforms and selling unsafe food for the enterprises.

Case 10. When $(pF_2 + pL) - (c_H - c_L) < 0$, $(\alpha F_1 + pF_2 + pL) - (c_H - c_L) > 0$, $qF_3 - c_P < 0$, and $\alpha F_1 + qF_3 - c_P > 0$ the system evolutionary stability of local equilibrium point is shown in Table 16.

As shown in Case 10, when the parameters meet: (1) the sum of the fines undertaken by illegal enterprises who are investigated by the government and the income loss of rectification is less than the difference between the cost of selling

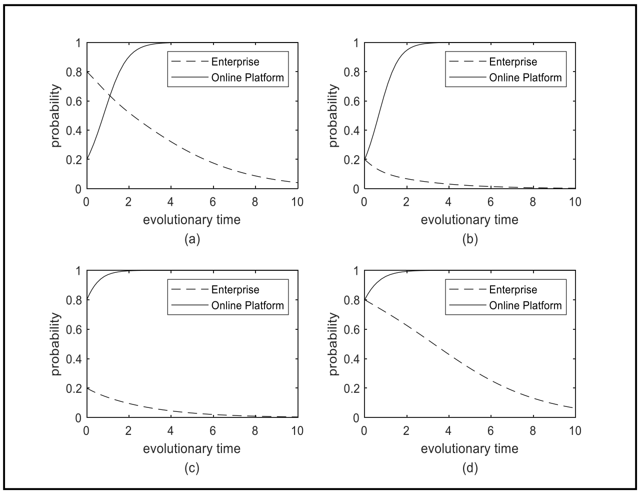

FIGURE 9. **Simulation results of evolutionary stability point in Case 9. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

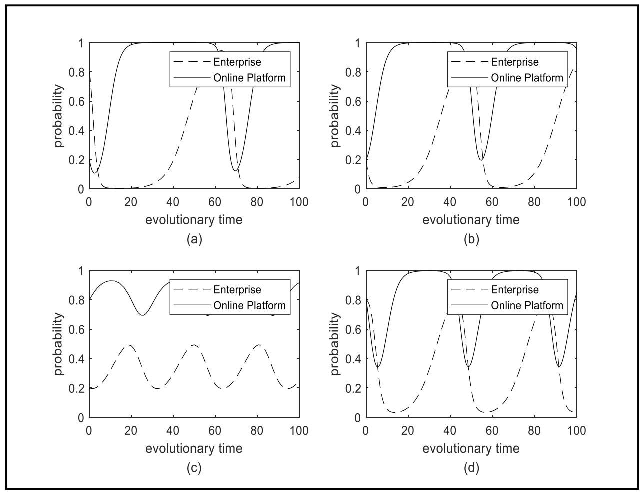

FIGURE 10. **Simulation results of evolutionary stability point in Case 10. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

TABLE 16. **System evolutionary stability analysis in Case 10.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	-	Uncertain	Saddle point
(0,1)	-	Uncertain	Saddle point
(1,0)	-	Uncertain	Saddle point
(1,1)	-	Uncertain	Saddle point

TABLE 17. **System evolutionary stability analysis in Case 11.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	-	Uncertain	Saddle point
(0,1)	-	Uncertain	Saddle point
(1,0)	+	-	ESS
(1,1)	+	+	Unstable point

safe food and unsafe food; (2) the sum of the fines undertaken by illegal enterprises who are investigated by both platform and government, as well as the income loss of rectification is greater than the difference between the cost of selling safe food and unsafe food; (3) the punishment imposed by the government on passive platform is less than the platform's supervision input; (4) the sum of the punishment imposed by the platform on illegal enterprises and the punishment imposed by the government on passive platforms is greater than the cost input of the active supervision of the platforms, there is no evolutionary stability strategy (ESS) in the system.

Assuming $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.2, p = 0.2, q = 0.6, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$. The simulation results of evolutionary stability in case 10 is shown in Figure 10. From the presented figures, it can be found that no matter what the initial state is, there is no evolutionary stability strategy. Both the platform and the enterprise show a periodic oscillation trend.

Case 11. When $(pF_2 + pL) - (c_H - c_L) < 0, (\alpha F_1 + pF_2 + pL) - (c_H - c_L) < 0, qF_3 - c_P < 0$, and $\alpha F_1 + qF_3 - c_P > 0$ the system evolutionary stability of local equilibrium point is shown in Table 17.

As shown in Case 11, when the parameters meet: (1) the sum of the fines undertaken by illegal enterprises who are investigated by both platform and government, as well as the income loss of rectification is less than the difference between the cost of selling safe food and unsafe food; (2) the punishment imposed by the government on passive platform is less than the platform's supervision input; (3) the sum of the punishment imposed by the platform on illegal enterprises and the punishment imposed by the government on passive platforms is greater than the cost input of the active supervision of the platforms, the evolutionary stable strategy (ESS) of the system is (1,0).

Assuming $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.1, p = 0.2, q = 0.6, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$. The simulation results of evolutionary stability in case 11 is shown in Figure 11. From the presented figures, it can be found that the choice of platforms behavior strategy has gradually moved towards 1 until reaching stability. And the behavior strategy of settled enterprises has gradually moved towards 0. The corresponding strategy combination is active supervision for the platforms and selling unsafe food for the enterprises.

Case 12. When $(pF_2 + pL) - (c_H - c_L) < 0, (\alpha F_1 + pF_2 + pL) - (c_H - c_L) > 0, qF_3 - c_P < 0$, and $\alpha F_1 + qF_3 - c_P < 0$ the system evolutionary stability of local equilibrium point is shown in Table 18.

Case 13. When $(pF_2 + pL) - (c_H - c_L) < 0, (\alpha F_1 + pF_2 + pL) - (c_H - c_L) < 0, qF_3 - c_P < 0$, and $\alpha F_1 + qF_3 - c_P < 0$ the system evolutionary stability of local equilibrium point is shown in Table 19.

As shown in Case 12 and Case 13, when the parameters meet: (1) the sum of the fines undertaken by illegal enterprises who are investigated by the government and the income loss

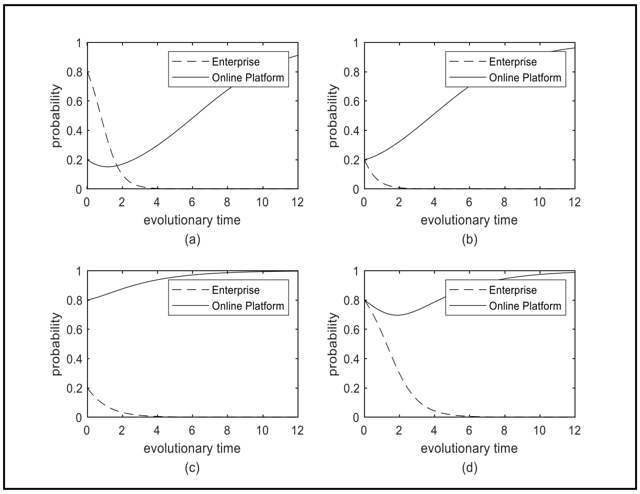

FIGURE 11. **Simulation results of evolutionary stability point in Case 11. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

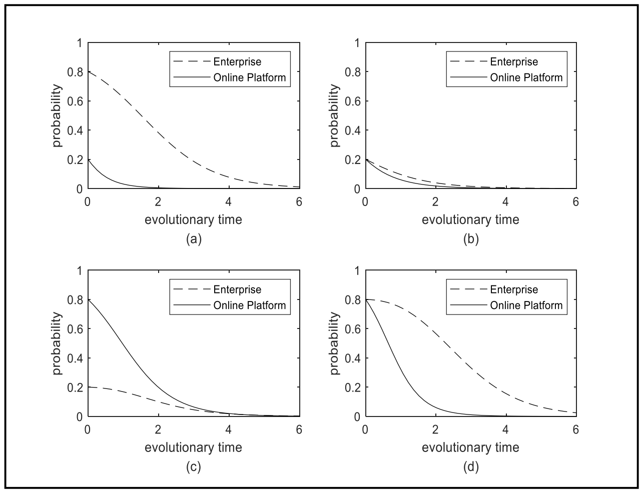

FIGURE 12. **Simulation results of evolutionary stability point in Case 12. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

TABLE 18. **System evolutionary stability analysis in Case 12.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	+	-	ESS
(0,1)	-	Uncertain	Saddle point
(1,0)	+	+	Unstable point
(1,1)	-	Uncertain	Saddle point

TABLE 19. **System evolutionary stability analysis in Case 13.**

Equilibrium Point	$det\|J\|$	$tr\|J\|$	Results
(0,0)	+	-	ESS
(0,1)	-	Uncertain	Saddle point
(1,0)	-	Uncertain	Saddle point
(1,1)	+	+	Unstable point

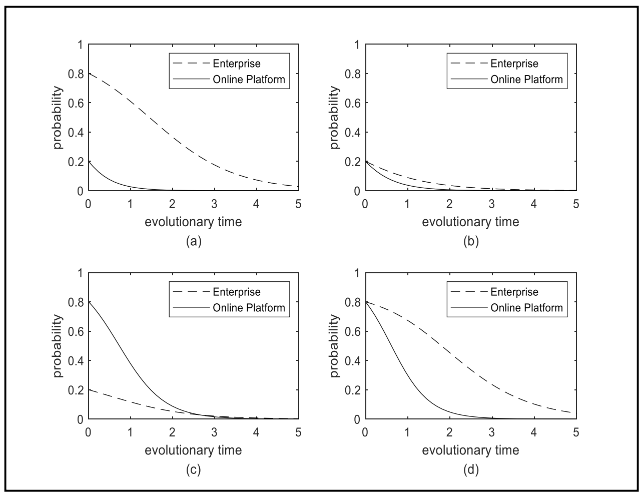

FIGURE 13. **Simulation results of evolutionary stability point in Case 13. (a)$x_0 = 0.2, y_0 = 0.8$; (b)$x_0 = 0.2, y_0 = 0.2$; (c)$x_0 = 0.8, y_0 = 0.2$; (d)$x_0 = 0.8, y_0 = 0.8$.**

of rectification is less than the difference between the cost of selling safe food and unsafe food; (2) the punishment imposed by the government on passive platforms is less than the platforms' supervision input; and (3) the sum of the punishment imposed by the platforms on illegal enterprises and the punishment imposed by the government on passive platforms is less than the cost input of the active supervision of the platforms, the evolutionary stable strategy (ESS) of the system is (0,0).

Assuming $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.2, p = 0.2, q = 0.2, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$ satisfy case 12,while $b = 25, E = 5, c_H = 8, c_L = 5, c_P = 5, \alpha = 0.1, p = 0.2, q = 0.2, F_1 = 6, F_2 = 7, F_3 = 8, L = 3$ meet case 13. The simulation results of evolutionary stability in case 12 and 13 is shown in Figure 12 and Figure 13. From the presented figures, we can see that no matter what the initial state is, it is not difficult to find that the choices of evolutionary behavior strategy for both sides of the game gradually approaches 0 from the initial value. The corresponding strategy combination is passive supervision for the platforms and selling unsafe food for the enterprises.

V. CONCLUSION

Based on the online food safety governance, a two-stage evolutionary game model under the SGM and the CGM was constructed, and the dynamic evolutionary path of the game system as well as the evolutionary stable strategies between the online platforms and the enterprises were analyzed. The conclusions of our study are as follows:

Firstly, under the SGM where the platforms are considered as the only governance sectors, although the performance of online food safety governance can be improved by increasing the platform discovery probability and platform penalty, the food enterprises cannot achieve sustainable provision of safe food cause the consistency of interests between the platforms and the enterprises. Thus, the performance of platforms single governance is not ideal.

Secondly, under the CGM where the platforms and the government jointly participate in governance, the overall safety environment of online food market can be improved. When the co-governance mode meet the following two conditions, food enterprises in the online market can continue selling safe food: (1) the loss caused by government supervision to the illegal enterprises is greater than the difference between the cost of the enterprises to sell safe food and unsafe food; (2) the loss caused by the co-governance of the platforms and the government to the illegal enterprises is greater than the difference between the cost of the enterprises to sell safe food and unsafe food, meanwhile, the penalty imposed by the government on the passive platforms is greater than the supervision cost input of active platforms. At this time, it is found that increasing the government's probability of discovering illegal enterprises and passive regulatory platforms and increasing the government penalties for illegal enterprises and passive regulatory platforms can all improve the online food market's safety to a certain extent. Besides, the government can also improve the online food market's security by increasing the use of measures to suspend enterprises for rectification. The research revealed that the sufficient supply of safe food in the online market under CGM might depend significantly on the intensity of government supervision and the punishment of enterprises and platforms. Under CGM, government supervision may play a more significant role in promoting food safety in the online market.

In this research, we focused on the game between the co-governance of platforms, enterprises and the government. In the real regulatory environment, subjects of online food market under co-governance mode may not limit to the mentioned parties in this paper. Stakeholders such as the industrial association and the media are also parties worth to study in the future research.

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