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Three-Party Evolutionary Game Analysis of the Government Reward and Punishment in Takeaway Food Safety Quality Regulation Under the Platform Economy

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Abstract: Food safety is an important guarantee for national stability and development. In recent years, with the popularization of mobile networks, the online food delivery industry has flourished. However, due to issues such as the improper management of food delivery businesses and weak regulation, the problem of food safety in the online food delivery industry has become increasingly prominent. This article addresses the situation where both the government and third-party ordering platforms are involved in regulation. It constructs a tripartite evolutionary game model among the food delivery producers, third-party ordering platforms, and government regulatory departments, and analyzes the evolutionary stability of the strategic choices made by each participant. The research findings are as follows: 1) Increasing the incentives and penalties by the government contributes to the production of safe food by the food delivery businesses and encourages the active participation of third-party food delivery platforms in regulation. However, a larger incentive may hinder the government's own regulatory responsibilities. 2) The government must establish reasonable incentive and penalty mechanisms that ensure the sum of incentives and penalties is greater than the speculative gains of all parties in order to guarantee food safety in the evolving and stable market environment of food delivery. Finally, Matlab 2021a is used for simulation analysis, in order to provide some suggestions for solving the safety problems of takeaway food in our country.

Keywords: Platform economy; takeaway food safety; quality regulation; three-party evolution game; simulation analysis

1. Introduction

In the "14th Five-Year Plan" and the "Long Range Objectives Through the Year 2035," the country clearly proposes to "comprehensively promote the construction of a Healthy China" and emphasizes the need to "prioritize the strategic position of safeguarding people's health." Ensuring food safety is an extremely important aspect in achieving the goals outlined in the plan[1].

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The reason is that food safety is a major livelihood issue, affecting people's lives and the future development of the country[2]. In recent years, with the development of modern information technology such as the Internet and big data, third-party ordering platforms have expanded rapidly under the impetus of platform economy. However, due to the characteristics of the Internet platform economy, food safety problems are increasingly serious. Insufficient government regulation of such emerging industries has led to a series of frequent food safety incidents, seriously affecting consumer health and the normal operation of the food market[3]. Traditional economics believes that government regulation is a necessary means to compensate for market failure[4], but now puts forward the concept of "social governance", emphasizing the full play of the role of multi-party supervision, and promote the governance model from the government-led to the "government-led, social synergy, public participation "government-led, social collaboration, public participation" synergistic governance change[5].

Around the "social governance", scholars at home and abroad have studied the impact of government rewards and punishments on food safety of takeaways; Caduff believes that the government needs to introduce public policies to maintain food safety, Losasso points out that consumers play an important role in food safety regulation, and Mensah believes that the government and enterprises should be linked to regulate and solve problems[6]. Zhou Guangliang, on the other hand, studied the path of national food safety regulation and emphasized that the synergistic governance of government, market and society is the key to solving food safety problems[7].

The above studies, while confirming that social co-governance significantly contributes to takeaway food safety, have rarely addressed the dynamic game between takeaway merchants, third-party ordering platforms, and the government, as well as the impact of the government's different regulatory strategies on takeaway merchants and third-party ordering platforms on takeaway food safety. Although Hu Chunhua[8] and others, by adopting an evolutionary game approach, considered that the government's penalty for safety regulation of online food ordering platforms would be conducive to increasing the platform's motivation to participate in the regulation as well as the merchants' motivation to operate in a self-disciplined manner. However, takeaway food safety is not a static issue at a point in time, and dynamic evolutionary thinking should be used to analyze its characteristics at different stages and focus on the regulatory coordination between the government and third-party takeaway platforms. In addition, for the subjects involved in regulatory coordination, most scholars generally agree that food safety as a public good should be provided by the government[9], and the government plays a very important role in the regulation of food safety system. For example, the government can effectively alleviate food safety problems by increasing the probability of inspection of enterprises and increasing the penalty for non-self-regulation[10].

Regarding the research on takeaway food safety, Wang Yong and Liu Hang et al. argue that the relationship between the government and the platform is not a simple substitution or complementary relationship, and that the government should strengthen the regulation of the market when the platform has a weak monitoring ability[11]. In order to describe the evolutionary process of takeaway food safety more precisely, an evolutionary game is introduced to consider the strategy selection at the stability point of mixed strategies. Zhu Lilong et al. further investigated the rent-seeking phenomenon in drug testing and proposed various regulatory measures and the role of third-party participation in regulation, which provided the government with countermeasures and suggestions for efficient regulation[12]. However, regarding takeaway food safety, further research is needed to investigate the impact of takeaway merchants' strategic choices on takeaway food safety when both government and third-party platform regulation exist.

2. Model Hypothesis and Construction

2.1 Model Hypothesis

In order to construct the game model and analyze the stability of each party's strategy and equilibrium point, the following hypotheses are made:

Hypothesis 1: The three parties involved in the game: the takeaway producer, the third-party ordering platform and the government are all finite rational subjects and evolve into optimal strategies over time.

Hypothesis 2: Assume that the takeaway producer has two strategies: safe production and unsafe production, noting that the probability of these two strategies is x, 1-x in turn; the third-party ordering platform, which chooses how to regulate the takeaway producer. The strategy space of its behavior is noted as {positive regulation, negative regulation}, and the probabilities of the corresponding strategies are y, 1-y in order; there are two strategies for the government {strict regulation, ignore regulation}, and the probabilities of the corresponding strategies are z, 1-z in order, where x,y,z are in the range 0 to 1.

Hypothesis 3: The takeout producer's revenue from selling takeout through the platform is R. The cost of providing quality-safe food is C_{ph}. The cost of providing quality-unsafe food is C_{pl}. When the takeaway producer provides quality-safe food, the ordering platform and the governmental pass the inspection; when the takeaway producer provides quality-safe unqualified food, it will rent-seeking from the third-party ordering platform in order to qualify for the shelves through the inspection. The rent-seeking cost is B, $B<(C_{ph}-C_{pl})$, and speculation in undisciplined production will generate speculative cost, which is set at C_1 for takeaway producer.

Hypothesis 4: The detection benefit of the third-party ordering platform is V. When the takeaway producer does not self-regulate production, if the ordering platform refuses to rent-seeking, the detection fails. If the ordering platform intends to rent-seek, it will engage in rent-seeking behavior with the takeaway producer. The speculative cost of the third-party ordering platform's intention to rent-seeking is C_2, which mainly includes the costs of falsifying testing records and issuing false reports.

Hypothesis 5: When the government pays attention to regulation, takeaway producers are fined for providing unsafe food F_p and negatively regulated third-party ordering platforms are fined F_t. Takeaway producers who provide safe food are rewarded M_p and reward actively regulated ordering platforms M_t. When the government neglects to regulate, there is no access to information on strategy choice. It is assumed that strict government regulation would cost C_3.

Hypothesis 6: If the government, platforms and takeaway producers all fulfill their responsibilities, it will benefit consumer health, economic development and social stability. At the same time, it will bring social benefits of value A to the government. Consumers' health is at risk when both takeaways and platforms fail to act in their own interests, and it costs the government C_4 to rectify this phenomenon. When the government adopts a strategy of neglecting to regulate, resulting in a lack of regulation , will be penalized by higher authorities for their own inaction, denoted by u ($u>C_4$).

2.2 Model Construction

Based on the above hypotheses, the mixed strategy game matrix of takeaway producers, third-party ordering platforms and government, as shown in Table 1.

Table 1 Three parties mixed-strategy game matrix

Strategy combination	Takeaway producers	Third-party ordering platforms	Government
(safe, active, strict)	$R-C_{ph}+M_p$	$V+M_t$	$A-C_3-M_p-M_t$
(safe, active, ignore)	$R-C_{ph}$	V	A
(safe, negative, strict)	$R-C_{ph}+M_p$	$V-C_2-F_t$	$A-C_3-M_p+F_t$
(safe, negative, ignore)	$R-C_{ph}$	$V-C_2$	A
(unsafe, active, strict)	$-C_{pl}-F_p-C_1$	$V+M_t$	$-C_3-M_t+F_p$
(unsafe, active, ignore)	$-C_{pl}-C_1$	V	0
(unsafe,negative,strict)	$R-C_{pl}-F_p-B-C_1$	$V-C_2-F_t+B$	$-C_3+F_t+F_p-C_4$
(unsafe,negative,ignore)	$R-C_{pl}-C_1-B$	$V-C_2+B$	$-C_4-u$

3. Model solution

3.1 Replicated dynamic equations

The replication dynamic equation can describe how individuals with different strategies compete with each other in a group to evolve the final group strategy.

The expected returns and average expected returns (U_1, U_2, U) of takeaway producers providing quality safe or quality unsafe food are as follows:

$U_1=yz[R-C_{ph}+M_p]+y(1-z)[R-C_{ph}]+(1-y)z[R-C_{ph}+M_p]+(1-y)(1-z)[R-C_{ph}]$

$U_2=yz[-C_{pl}-F_p-C_1]+y(1-z)[-C_{pl}-C_1]+(1-y)z[R-C_{pl}-F_p-C_1-B]+(1-y)(1-z)[R-C_{pl}-C_1-B]$

$U=xU_1+(1-x)U_2$

Similarly, the expected returns W_1 and W_2 for positive and negative regulation of third-party ordering platforms, and the average expected return W are:

$W_1=x[z(V+M_t)+(1-z)V]+(1-x)[z(V+M_t)+(1-z)V]$

$W_2=x[z(V-C_2-F_t)+(1-z)(V-C_2)]+(1-x)[z(V-C_2-F_t+B)+(1-z)(V-C_2+B)]$

$W=yW_1+(1-y)W_2$

Similarly, the expected returns E_1 and E_2, and the average expected return E for strict and negligent regulation by government are respectively:

$E_1=xy(A-C_3-M_p-M_t)+x(1-y)(A-C_3-M_p+F_t)+(1-x)y(-C_3-M_t+F_p)+(1-x)(1-y)(-C_3+F_t+F_p-C_4)$

$E_2=xyA+x(1-y)A+(1-x)(1-y)(-C_4-u)$

$E=zE_1+(1-z)E_2$

Then a system of equations is formed from the above three replicated dynamic equations as shown below:

$$F(x)=\frac{dx}{dt}=x(x-1)[C_{ph}-C_{pl}-C_1-B-y(R-B)-z(F_p+M_p)]$$

$$F(y)=\frac{dy}{dt}=y(y-1)[(1-x)B-z(F_t+M_t)-C_2]$$

$$F(z)=\frac{dz}{dt}=z(z-1)[C_3-u-F_t-F_p+x(M_p+F_p+u)+y(M_t+F_t+u)-xyu]$$

3.2 Equilibrium point and stability analysis

The equilibrium points of the system can be obtained from F(x)=0, F(y)=0, F(z)=0: $E_1(0,0,0)$, $E_2(1,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$, $E_5(1,1,0)$, $E_6(1,0,1)$, $E_7(0,1,1)$, $E_8(1,1,1)$, $E_9(0,(u+F_t+F_p-C_3)/(M_t+F_t+u),(B-C_2)/(M_t+F_t)$, $E_{10}((F_t+F_p+u-C_3)/(M_p+F_p),0,(C_{ph}-C_{pl}-C_1-B)/(M_p+F_p))$, $E_{11}((F_p-C_3-M_t)/(M_p+F_p),1,(C_{ph}-C_{pl}-C_1-R)/(M_p+F_p))$, $E_{12}((B-C_2)/B,(C_{ph}-C_{pl}-C_1-B)/(R-B),0)$, $E_{13}((B-F_t-M_t-C_2)/B,(C_{ph}-C_{pl}-C_1-B-F_p-M_p)/(R-B),1)$. Since x, y, z∈[0,1], then E9 to E13 are meaningful under certain conditions, and since $(C_{ph}-C_{pl}-C_1-R) < 0$, then E_{11} is meaningless.

The Jacobian matrix of the three-party evolutionary game system is

$$J=\begin{bmatrix} J_1 & J_2 & J_3 \\ J_4 & J_5 & J_6 \\ J_7 & J_8 & J_9 \end{bmatrix}=\begin{bmatrix} \partial F(x)/\partial x & \partial F(x)/\partial y & \partial F(x)/\partial z \\ \partial F(y)/\partial x & \partial F(y)/\partial y & \partial F(y)/\partial z \\ \partial F(z)/\partial x & \partial F(z)/\partial y & \partial F(z)/\partial z \end{bmatrix}=\begin{bmatrix} \begin{matrix}(2x-1)[C_{ph}-C_{pl}-C_1-B \\ -y(R-B)-z(F_p+M_p)]\end{matrix} & x(x-1)[B-R] & x(x-1)[-F_p-M_p] \\ y(y-1)[-B] & \begin{matrix}(2y-1)[(1-x)B \\ -z(F_t+M_t)-C_1]\end{matrix} & y(y-1)[-F_t-M_t] \\ z(z-1)[M_p+F_p+u-yu] & z(z-1)[M_t+F_t+u-xu] & \begin{matrix}(2z-1)[C_3-u-F_t-F_p+ \\ x(M_p+F_p+u)+y(M_t+F_t+u)-xyu]\end{matrix} \end{bmatrix}$$

According to Lyapunov's first method, when all the eigenvalues of the Jacobian matrix are less than 0, the point is an evolution-stable strategy. When the Jacobian matrix has positive eigenvalues, the equilibrium point is unstable. The stability of each equilibrium point is analyzed, as shown in Table 2.

Table 2 Stability analysis of equilibrium points

Balance points	Jacobian matrix eigenvalues		Stability conclusions	conditions
	λ_1, λ_2, λ_3	Real symbol		
$E_1(0,0,0)$	$C_{pl}-C_{ph}+C_1+B, -B+C_2, F_p+F_t+u-C_3$	$(-,-,+)$	unstable point	\
$E_2(1,0,0)$	$C_{ph}-C_{pl}-C_1-B, C_2, F_t-C_3-M_p$	$(+,+,\times)$	unstable point	\
$E_3(0,1,0)$	$C_{pl}-C_{ph}+C_1+R, B-C_2, F_t-C_3-M_t$	$(+,+,\times)$	unstable point	\
$E_4(0,0,1)$	$C_{pl}-C_{ph}+C_1+B+F_p+M_p, F_t+C_2+M_t-B, C_3-u-F_t-F_p$	$(-,-,-)$	ESS	①
$E_5(1,1,0)$	$C_{ph}-C_{pl}-C_1-R, -C_2, -C_3-M_p-M_t$	$(-,-,-)$	ESS	\
$E_6(1,0,1)$	$C_{ph}-C_{pl}-C_1-B-F_p-M_p, F_t+C_2+M_t, C_3+M_p-F_t$	$(\times,+,\times)$	unstable point	\
$E_7(0,1,1)$	$C_{pl}-C_{ph}+C_1+R+F_p+M_p, B-M_t-F_t-C_2, C_3+M_t-F_p$	$(+,\times,\times)$	unstable point	\
$E_8(1,1,1)$	$C_{ph}-C_{pl}-C_1-R-F_p-M_p, -F_t-C_2-M_t, C_3+M_p+M_t$	$(-,-,+)$	unstable point	\
$E_9(0,y_1,z_1)$	$\alpha_1, \lambda_2=\lambda_3=\sqrt{y_1(1-y_1)(F_t+M_t)z_1(1-z_1)(M_t+F_t+u)}\bullet i$	$(-,0,0)$	uncertainty	②
$E_{10}(x_1,0,z_2)$	$\alpha_2, \lambda_2=\lambda_3=\sqrt{x_1(1-x_1)(F_p+M_p)z_2(1-z_2)(M_p+F_p+u)}\bullet i$	$(-,0,0)$	uncertainty	③
$E_{12}(x_2,y_2,0)$	$\alpha_3, \lambda_2=-\lambda_3=\sqrt{x_2(1-x_2)(R-B)y_2(1-y_2)B}$	$(\times,+,-)$	unstable point	④
$E_{13}(x_3,y_3,1)$	$\alpha_4, \lambda_2=-\lambda_3=\sqrt{x_3(1-x_3)(R-B)y_3(1-y_3)B}$	$(\times,+,-)$	unstable point	⑤

Note: x denotes that the sign is uncertain, x_1, x_2, x_3, y_1, y_2, y_3, z_1, z_2 are the coordinates of the corresponding equilibrium point, which is unstable or meaningless if the equilibrium point corresponding to the hair condition is not satisfied. ① $C_{pl}-C_{ph}+C_1+B+F_p+M_p<0$, $F_t+C_2+M_t-B<0$; ② $\alpha_1<0$, $F_p-C_3<M_t$, $B-C_2-M_t-F_t<0$; ③ $\alpha_2<0$, $F_t-C_3<M_p$, $C_{ph}-C_{pl}-C_1-B-F_p-M_p<0$; ④$B-C_2>0$, $C_{ph}-C_{pl}-C_1-B>0$; ⑤$B-M_t-F_t-C_2>0$, $C_{ph}-C_{pl}-C_1-B>0$.

Corollary 1: When C_{pl}-C_{ph}+C_1+B+F_p+M_p<0 and F_t+C_2+M_t-B<0, according to Table 2, $E_4(0,0,1)$ and $E_5(1,1,0)$ are the two stabilization points of the replicated dynamic system. Equilibrium points $E_9(0,y_1,z_1)$ and $E_{10}(x_1,0,z_2)$ are meaningless, while $E_{12}(x_2,y_2,0)$ and $E_{13}(x_3,y_3,1)$ are unstable.

This suggests that when the government sets smaller rewards and penalties or when the takeaway producer tries to avoid the regulatory gains of the third-party ordering platform, depending on the initial point, the system's strategy combinations will stabilize at two stable points (providing unsafe food, negative supervision and strict supervision) and (providing safe food, active supervision and ignoring supervision). At this point, the government's regulation fails to constrain the violation behaviors of takeout producers and third-party ordering platforms. In order to avoid the emergence of the stable strategy combination E4(0,0,1), the government regulator must set a sufficiently large amount of fines or rewards and penalties to play the role of active regulation.

Corollary 2: When F_p+M_p>C_{ph}-C_{pl}-C_1-B>0 and F_t+M_t>B-C_2>0, there exists at least one stabilization point $E_5(1,1,0)$ of the system, and at the same time, when F_p-M_t>C_3 and F_t-M_p>C_3 are satisfied, there is only one stabilization point $E_5(1,1,0)$.

According to table 2, at this time, conditions ① and ⑤ are not satisfied, then $E_4(0,0,1)$ is an unstable point, and $E_{13}(x_3,y_3,1)$ is meaningless; at this time, condition ④ is satisfied, then $E_{12}(x_2,y_2,0)$ is an unstable point; conditions ② and ③ need to be judged by more elements of the conditions, so that the stability of $E_9(0,y_1,z_1)$, $E_{10}(x_1,0,z_2)$ cannot be be judged. For the replicated dynamic system, when the conditions F_p-M_t>C_3 and F_t-M_p>C_3 are increased, conditions ② and ③ are not satisfied, and $E_9(0,y_1,z_1)$, $E_{10}(x_1,0,z_2)$ are meaningless, so there exists only one stabilization point $E_5(1,1,0)$. This suggests that the sum of government fines and incentives for takeout producers and third-party ordering platforms should be at least higher than the revenue generated by their respective regulatory evasions in order to effectively prevent the system from having a combination of strategies (providing unsafe food, negative regulation, strict regulation).

4. Model simulation

In order to verify the validity of the evolutionary stability analysis, the model was assigned numerical values in conjunction with the real situation and numerical simulation was carried out using Matlab2021a. Array 1 is assigned values R=50, C_{ph}-C_{pl}=25, C_1=5, B=15, F_p=10, M_p=10, C_2=5, F_t=10, M_t=5, C_3=5, u=15, which satisfies the conditions in Corollary 2. On the basis of Array 1, the influence of the changes of F_t, M_t and M_p on the evolution process and results are discussed respectively.

First, the simulation results are shown in Fig. 1 for F_t = 0, 10, 20, and. in Fig. 2 for M_t = 0, 5, 10.

Figure 1 shows that the probability of self-regulated production by takeaway producers is gradually stabilized at 1 as F_t increases during the evolutionary process. In this process, the probability that the government chooses to strictly regulate gradually increases to a certain peak and then starts to decline to 0, while the probability that the third-party ordering platform chooses to regulate actively is gradually increasing. Figure 2 shows that M_t increases will make the government tend to choose to ignore regulation. Therefore, the government should formulate a reasonable reward and punishment system according to the actual situation, so that the third-party food ordering platforms can also actively participate in the regulation, and jointly protect the takeaway food safety.

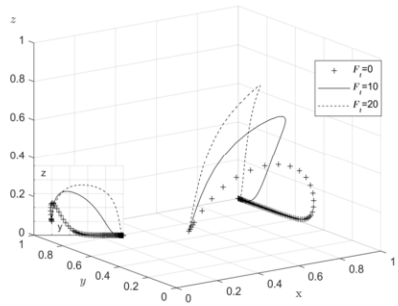

Figure 1 Impact of government fines for third-party ordering platforms

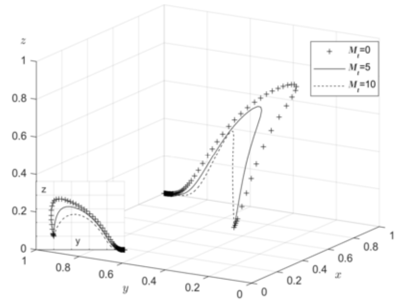

Figure 2 Impact of government incentives for third-party ordering platform

Next, the simulation results of replicating the system of dynamic equations evolving over time 50 times are shown in Fig. 3 by assigning $M_p = 0, 10, 20$ respectively.

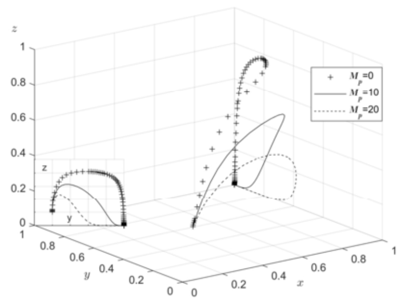

Figure 3 Impact of government incentives for takeaway producers

Figure 3 shows that during evolutionary stabilization, as M_p increases the government will gradually tend to choose to ignore regulation, and the third-party food ordering platform is more likely to choose negative regulation.

Since array 1 satisfies the conditions in Corollary 2, Corollary 2 can be verified. To verify Corollary 1, given array 2: R=50, C_{ph}-C_{pl}=35, C_1=5, B=16, F_p=8, M_p=5, C_2=5, F_t=6, M_t=4, C_3=5, u=15 satisfy its conditions, and letting each of the two sets of values evolve over time 50 times yields the results shown in Figures 4-5.

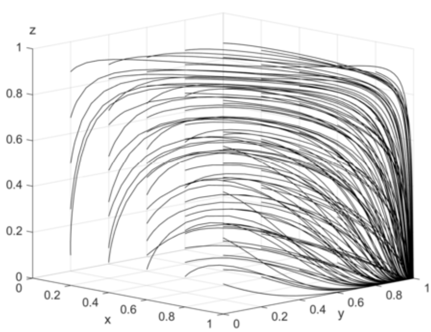
Figure 4 Array 1 evolves 50 times as a result

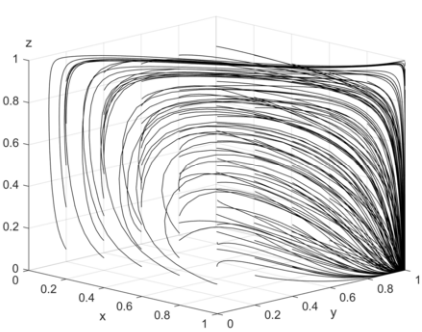
Figure 5 Array 2 evolves 50 times as a result

As can be seen in Figure 4, $E_{10}(x_1,0,z_2)$ is an unstable equilibrium point, and there is only one evolutionarily stable strategy combination (providing safe food, active supervision, and ignore supervision) that satisfies the conclusion of Corollary 2. Figure

5 shows that there are two evolutionary stable points (0,0,1), and (1,1,0) in the system under condition ①. Therefore, the regulator should examine the interests of takeaway producers and third-party ordering platforms from various aspects to ensure that the sum of rewards and penalties for each party is higher than the benefits generated by their circumvention of regulation, so as to avoid the phenomenon that takeaway producers do not exercise self-discipline to make low-quality takeaway food jeopardize consumers. It can be seen that the simulation analysis can more intuitively reflect the strategic stability analysis of the evolutionary game, which is of practical guidance significance for the regulation of takeaway food quality.

5. Conclusion

Taking takeaway food safety supervision as the research object, this paper constructs a tripartite evolutionary game based on the evolutionary game theory of takeaway producers—third-party ordering platforms—government, and discusses the influence of different influencing factors on the behaviors of all parties through simulation analysis. Finally, the following conclusions and suggestions are drawn. The government's incentives and penalties are conducive to the normative behavior of takeaway producers to provide high-quality food in a self-disciplined manner and third parties to actively regulate them; the incentives and penalties set by the government must comply with the condition that the sum of the incentives and penalties for each party is greater than the gains from their circumvention of the regulation in order to safeguard the safety of the takeaway food market.

This paper does not consider the participation of consumers in regulation, and future research can take consumers as a separate participant and consider the four-party evolutionary game among takeaway producers, the government, the third-party ordering platforms and consumers. In addition, in the numerical simulation, the given data are only set according to the constraints based on the real situation, and no corresponding research has been carried out, so future research can be carried out according to the model to obtain the actual data for simulation.

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