SOFT COMPUTING IN DECISION MAKING AND IN MODELING IN ECONOMICS

Public health events emergency management supervision strategy considering citizens' and new media's different ways of participation

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Abstract

Public health events have done great harm. Emergency management requires the joint participation of multiple parties including government department, pharmaceutical enterprises, citizens and new media. Then, what are the effects of different strategy choices in participation of citizens and new media on emergency management? To answer the question, we construct a four-party evolutionary game model, considering the citizens' two participation ways consisted of true evaluation and false evaluation, and the new media's two participation ways consisted of report after verification and report without verification. This is of more practical significance than simply studying whether citizens and new media participate in emergency management or not because citizen and new media participation does not represent the completely positive behavior. Then, we conduct the evolutionary stability analysis, solve the stable equilibrium points using the *Lyapunov first method* and conduct the simulation analysis with *MATLAB 2020b*. The results show that, firstly, the greater the probability of citizens making true evaluation, the more inclined the government department is to strictly implement the emergency management system; secondly, when the probability of citizens making true evaluation decreases, new media are more inclined to report after verification, and when new media lose more pageview value or should be punished more for reporting without verification, the probability that they report without verification is smaller; thirdly, the greater the probability of citizens making false evaluation, the less enthusiasm of pharmaceutical enterprises to participate in emergency management, which indicates that false evaluation is detrimental to prompt pharmaceutical enterprises to participate; what's more, the greater the probability of new media reporting after verification, the greater the probability of pharmaceutical enterprises actively participating, which shows that new media's verification to citizens' evaluation is beneficial to emergency management.

Keywords Public health events · Emergency management · Supervision strategy · Evolutionary game · Simulation analysis

1 Introduction

In recent years, public health events have occurred frequently around the world, such as SARS in 2003, Influenza A (H1N1) in 2009, Middle East Respiratory Syndrome in 2012, Ebola virus in 2014, Zika virus in 2016 and COVID-19 in late 2019. The outbreak and spread of public health events have seriously endangered the citizen health, economic development, social stability and national security. How to conduct the emergency management has become an urgent problem to be solved in every country and region.

To deal with public health events, the World Health Organization (WHO) has published *Framework for a Public Health Emergency Operations Centre*, which provides high-level methodological guidance for the design, development and strengthening of public health emergency management agencies in order to achieve a "goal-oriented" response. In the USA, Metropolitan Medical Response System (MMRS) is an important system in the emergency management of public health events. According to the needs of the Federal Ministry of Health, local governments have set up the emergency committees and

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established the sound infectious disease notification system and complete medical response system. The European Union has established the Early Warning and Emergency Response System (EWRS) and the European Centre for Disease Prevention and Control (ECDC), which form the emergency management system for infectious diseases. Among them, Germany established the STAKOB (Center for Capacity and Treatment of Serious Infectious Diseases) to assess, investigate and respond to public health events. Australia has built an emergency management system at the federal government, state and local governments and community levels, and issued *the National Health Emergency Response Arrangement*, which outlines the executive departments, responsibility and arrangements for public health events to strengthen the monitoring mechanism and emergency management system. Japan has used advanced science and technology to monitor potential risks of public health events and further improved the timeliness and accuracy of emergency information through information sharing platform. China has established the State Bureau for Disease Control and Prevention, which is responsible for formulating policies on the prevention and control of infectious diseases and public health supervision, planning the construction of the monitoring and early warning system for public health events and guiding public health supervision and management.

To sum up, government department plays a leading role in the emergency management of public health events and is responsible for establishing and improving the emergency management system. However, public health events are highly professional, and the basis of emergency management is the scientific allocation and strong guarantee of drugs, vaccines and other supplies, which require the active participation of pharmaceutical enterprises. In addition, with the rapid development of the Internet, new media have the strong ability to collect and disseminate information. As the main body of public opinion supervision, the citizens can feed back their own information to new media and exert public opinion influence on government department and pharmaceutical enterprises through new media's report.

Therefore, we consider new media's and citizens' different ways of participation, and construct an evolutionary game model involving the government department, pharmaceutical enterprises, citizens and new media. The stable equilibrium points of each game player's strategy choices are solved. The evolutionary stability and the influence of relevant parameters on the game player's strategy choices are analyzed. It aims to solve the following three problems. Firstly, how do the strategy choices of new media affect the behavior of government department, pharmaceutical enterprises and citizens in emergency management? Secondly, how do citizen participation ways

affect the strategy choices of government department, pharmaceutical enterprises and new media? Thirdly, what is the influence of pharmaceutical enterprises' strategy choices on the strategy choices of government department, citizens and new media?

The rest of our paper is organized as follows. In Sect. 2, we review relevant literature on public health events emergency management. And we make hypotheses and construct the game model in Sect. 3. Section 4 contains the evolutionary stability analysis of each player's strategy choices. Then Sect. 5 is the stability analysis of the equilibrium points for the whole replicator dynamic system. In Sect. 6, we use *MATLAB 2020b* to conduct numerical simulations and analyze the influence of parameters on the strategy choices of each game player. Finally, the discussion is in Sect. 7 and the conclusions are in Sect. 8.

2 Literature review

In today's increasingly interconnected world, outbreak of infectious diseases can spread widely and cause considerable impact on public health (Lu et al. 2019). To cope with public health events, scholars have carried out extensive studies on the participation of the government department, pharmaceutical enterprises, citizens and new media in emergency management.

Facing the public health events, to protect the citizen health and ensure the normal operation of the economy, the government needs to weigh controlling the spread of the virus against the economic cost of adopting strict containment measures (Comfort et al. 2020). Following the COVID-19 outbreak in late 2019, governments around the world attempted to contain the pandemic by implementing the large-scale non-pharmaceutical interventions (NPI) at the individual level of citizens (Wu et al. 2020; Brauner et al. 2021). Among them, the Chinese government implemented rapid and comprehensive public health emergency intervention measures, including the ban on travel to and from Wuhan, the suspension of urban public transport and so on (Chinazzi et al. 2020; Tian et al. 2020). In addition, Italy, the USA and many European countries also adopted non-pharmaceutical intervention measures, such as closing schools and city lockdowns, which has significantly delayed the growth of the epidemic and reduced the spread of the epidemic (Flaxman et al. 2020; Hsiang et al. 2020; Kraemer Moritz et al. 2020). Unlike those countries, the South Korean government didn't impose strict and enforced blockades on virus centers, but adopted transparent risk communication policies and mobilized public participation to contain the spread of the epidemic (Moon 2020).

In modern society, immunization is an indispensable mechanism for preventing infectious diseases caused by virus (Yong et al. 2020). Because of the novelty of virus, non-pharmaceutical interventions alone are not enough, so the rapid development and production of an effective vaccine is imperative to mitigate the effects of the epidemic on public health (Gao et al. 2020; Krammer 2020). It requires the active participation of pharmaceutical enterprises. In emergency management, pharmaceutical enterprises can balance their economic goals and social goals by actively assuming social responsibility and positive citizen evaluation on such behavior of enterprises can improve their reputation and bring more potential customers (Rodell et al. 2020; Maon et al. 2021). Citizen participation in emergency management can enable public services to be effectively provided. The factors that affect the degree of citizen participation include the citizen's personal psychological orientation and personal service needs (Uzochukwu et al. 2018). The citizens can participate in emergency management by sharing relevant information. Their sense of self-worth, social support and reputation enhancement have a positive impact on information sharing. Therefore, to give full play to the role of citizens in emergency management, the government should design a reasonable incentive mechanism to enhance the self-worth sense of citizens and social responsibility (Yan et al. 2016; Sjoberg et al. 2017).

Upgrading health reality is the responsibility of all, it is necessary to think about the design of a smart system based on modern technologies to reduce the time and effort exerted on the competent authorities in both health sectors furthermore (Al Janabi et al. 2021). The development of modern information and communication technology has provided new possibilities for citizen participation in emergency management (Zhang et al. 2019). There are a lot of data and information in the network (Al Janabi et al. 2020a, b, c). The use of social media impacts information accessibility, adaptability, proactiveness and resilience (Kavota et al. 2020). Intelligent analysis of prediction data mining techniques is widely used to support optimizing future decision-making in many different fields including healthcare and medical diagnoses (Mahdi and Al Janabi 2020; Al Janabi et al. 2020a, b, c; Al Janabi and Mahdi 2019). In emergency management of public health events, the use of social media by the citizens is booming, but whether this behavior has a positive or negative impact on emergency management has not been determined (Elbanna et al. 2019). Corporate reputation is an intangible asset for an enterprise, and the increase or decrease of reputation will bring value or loss (Wei et al. 2017). The rise of social media is changing the way corporate reputation is generated and spread in the public domain. Different ways of citizen evaluation and the enhancement of heterogeneity of media reputation will affect the formation of corporate reputation (Etter et al. 2019). New media can influence the reputation of enterprises through its ability to spread public opinion, bringing reputation value or reputation loss to enterprises, and thus affect the behavior and decision-making of enterprises (Blevins et al. 2019; Syed et al. 2019). The citizens can also participate in policy decision-making through social media. Government department should closely monitor the information on social media, attach importance to citizen participation and provide high-quality feedback (Lee et al. 2018; Liao et al. 2020).

To sum up, the existing literature mainly discusses the role of the government department, pharmaceutical enterprises, citizens and new media in the emergency management supervision from the perspective of a single party. There is still a lack of research that takes the government department, pharmaceutical enterprises, citizens and new media into account at the same time. In addition, the effect of citizens' and new media's different ways of participation on other participants was not taken into account.

As we all know, optimization is the act of getting the finest result beneath given circumstances (Al Janabi and Alkaim 2022). There are many optimization algorithms to find the best solutions (Al Janabi et al. 2020a, b, c). Comparison with previous works are as follows. Firstly, few previous works have used game theory to study emergency management supervision. And previous works of game theory were mostly limited to two-party static game under the condition that the game parties are completely rational, but we have extended it to four-party evolutionary game under the condition that the game parties are bounded rational. Therefore, in this paper, we consider the government department, pharmaceutical enterprises, citizens and new media as four players and construct a four-party game model under the condition that the four game parties are bounded rational. Secondly, considering the influence of citizens' true evaluation and false evaluation on the strategy choices of other participants, we analyze the evolutionary stability of government department, pharmaceutical enterprises, new media and citizens, and the stability equilibrium points under different conditions are solved (Rong et al. 2020; He et al. 2021). Finally, we conduct the simulation analysis with MATLAB 2020b to verify the influence of parameters on each game player's strategy choices and put forward suggestions for emergency management and supervision of public health events. To sum up, comparison with previous works is shown in Table 1.

Table 1 Comparison with previous works

Points	Previous works	Our work
Techniques	Two-party static game	Four-party evolutionary game
Hypotheses	Completely rational game participants	Bounded rational game participants
Analysis stage	Nash equilibrium of two participants	Evolutionary stability of four game participants, stability equilibrium points of strategy choices of replication dynamic systems, and simulation analysis
Results	From model analysis	Combined with model analysis and simulation analysis
Advantages	Pure strategy, dominant strategy and mixed strategy Nash equilibrium of two players can be obtained in the case of completely rationality of the participants	Take the four participants into account at the same time, and we study the interaction between different participants' strategy choices through model analysis. And the hypotheses are in the case of bounded rationality of the participants, which is more in line with reality
Disadvantages	In reality, the participants are often not completely rational	The game model is one-stage under the condition of bounded rationality and without considering the game sequence

3 Model hypothesis and construction

Under the background of new media, we consider citizen participation, and the logical relationship of the government department, pharmaceutical enterprises, citizens and new media is shown in Fig. 1.

From Fig. 1, we can get that the game parties include government department, pharmaceutical enterprises, citizens and new media. In emergency management, the relationship between government department and pharmaceutical enterprises are supervision and acceptance of supervision. Pharmaceutical enterprises provide product to citizens, and citizens will make true or false evaluation. New media accept the evaluation feedback by citizens, they can choose to report the evaluation after verification or without verification. New media can report the information about government departments as well. So, citizens

participate in the emergency management supervision by making evaluation and new media participate by report.

3.1 Model hypothesis

Based on emergency management of public health events, we construct an evolutionary game model involving the government department, pharmaceutical enterprises, citizens and new media. Then make the following hypotheses.

H1 Select the government department, pharmaceutical enterprises, citizens, and new media as the players of the game and the four players are bounded rational. The strategy choice space of government department is S_g = {Implement strictly, Not implement strictly}, i.e., S_g = {IS, NIS}. The strategy choice space of pharmaceutical enterprises is S_e = {Participate actively, Participate passively}, i.e., S_e = {PA, PP}. The strategy choice space of citizens is S_p = {Evaluate truly, Evaluate falsely}, i.e.,

Fig. 1 The logical relationship of the four-party game model. In this figure, we describe the logical relationship between the government department, pharmaceutical enterprises, citizens and new media in the emergency management and supervision of public health events
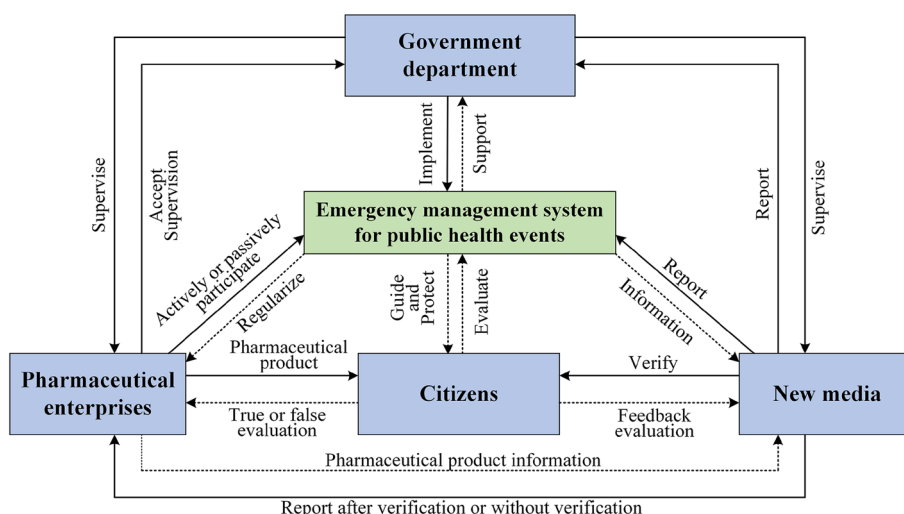
S_p = {ET, EF}. The strategy choice space of new media is S_m = {Report after verification, Report without verification}, i.e., S_m = {RAV, RWV}.

H2 The government department chooses "IS" with the probability of g, and chooses "NIS" with the probability of $(1 - g)$. The pharmaceutical enterprises choose "PA" with the probability of e, and choose "PP" with the probability of $(1 - e)$. The citizens choose "ET" with the probability of p, and choose "EF" with the probability of $(1 - p)$. The new media choose "RAV" with the probability of m, and choose "RWV" with the probability of $(1 - m)$. And $g, e, p, m \in [0, 1]$.

H3 When the government department doesn't strictly implement the emergency management system, it only pays the daily administrative cost C_g. When it strictly implements, it needs to pay additional supervision cost ΔC_g, and the subsidy it will obtain from the superior government is M_g. When pharmaceutical enterprises actively participate in emergency management, they can ensure the production capacity and quality, pay the cost C_{eh}, and obtain additional sales revenue R_e. When pharmaceutical enterprises passively participate, they pay the cost C_{el}, and $C_{el} < C_{eh}$. To encourage pharmaceutical enterprises to actively participate, the government department gives them subsidy M_e. If the pharmaceutical enterprises don't actively participate, they will be punished by the government department, and the punishment is F_e.

H4 The citizens can make evaluation on the behavior of pharmaceutical enterprises in emergency management, including true evaluation and false evaluation, and feedback the evaluation to new media, so as to expand the transmission speed and scope of evaluation. The new media will reward the citizens who provide true evaluation to encourage them to give true feedback, and the reward is set as V_p. The information value brought by the true evaluation of citizen feedback to new media is V_m. In addition, the cost of citizens making true evaluation is C_{pt}, and the cost of false evaluation is C_{pf}.

H5 As for the evaluation that citizens feedback, in order to ensure the authenticity of the report, new media may choose to report after verification, and the cost is C_{mh}. Or choose not to verify the report, in this case, the authenticity of the report can't be guaranteed, and the cost is C_{ml}, $C_{ml} < C_{mh}$. If new media choose report without verification, false evaluation will cause reputation loss D_e to the pharmaceutical enterprises. At this time, the pharmaceutical enterprises will sue the new media, and the punishment for new media is F_m. Besides, due to the new media's false report, the public credibility of new media will decline, and the citizens will pay less attention to new media. The new media will lose pageview value T_m.

H6 When pharmaceutical enterprises don't actively participate in emergency management, the true evaluation will damage their reputation and cause loss L_e to them. At this time, if the government department doesn't strictly implement the emergency management system, it will be punished by the superior government, and the punishment is F_g. When citizens make the false evaluation, if the new media verify it, they will expose the false evaluation, and they can obtain pageview revenue R_m. Then, the personal credit of citizens will be negatively affected, which will cause the loss of utility U_p, and they will also face punishment F_p.

Relevant parameters and meanings are shown in Table 2.

3.2 Model construction

Based on the above hypotheses, we construct a game matrix of the government department, pharmaceutical enterprises, citizens and new media in emergency management supervision, as shown in Table 3.

4 Model analysis

4.1 Evolutionary stability analysis of government department's strategy

The government department's expected return of choosing "Implement strictly" is

$$
\begin{aligned}
E_g =\ & epm(M_g - C_g - \Delta C_g - M_e) \\
& + ep(1 - m)(M_g - C_g - \Delta C_g - M_e) \\
& + e(1 - p)m(M_g - C_g - \Delta C_g - M_e) \\
& + e(1 - p)(1 - m)(M_g - C_g - \Delta C_g - M_e) \\
& + (1 - e)pm(M_g - C_g - \Delta C_g - M_e + F_e) \\
& + (1 - e)p(1 - m)(M_g - C_g - \Delta C_g - M_e + F_e) \\
& + (1 - e)(1 - p)m(M_g - C_g - \Delta C_g - M_e + F_e) \\
& + (1 - e)(1 - p)(1 - m)(M_g - C_g - \Delta C_g - M_e + F_e) \\
=\ & M_g - C_g - \Delta C_g - M_e + (1 - e)F_e
\end{aligned}
\tag{1}
$$

The government department's expected return of choosing "Not implement strictly" is

$$
\begin{aligned}
E_{1-g} =\ & epm(-C_g) + ep(1 - m)(-C_g) + e(1 - p)m(-C_g) \\
& + e(1 - p)(1 - m)(-C_g) + (1 - e)pm(-C_g - F_g) \\
& + (1 - e)p(1 - m)(-C_g - F_g) \\
& + (1 - e)(1 - p)m(-C_g) + (1 - e)(1 - p)(1 - m)(-C_g) \\
=\ & -C_g - (1 - e)pF_g
\end{aligned}
\tag{2}
$$

Table 2 Parameters and meanings

Parameter	Meaning	Parameter	Meaning
g	The probability that the government department chooses "Implement strictly"	F_e	The punishment when pharmaceutical enterprises passively participate
e	The probability that pharmaceutical enterprises choose "Participate actively"	L_e	The loss when pharmaceutical enterprises passively participate
p	The probability that citizens choose "Evaluate truly"	C_{pt}	The cost of citizens making true evaluation
m	The probability that new media choose "Report after verification"	C_{pf}	The cost of citizens making false evaluation
C_g	The daily administrative cost of government department not strictly implementing	U_p	The utility loss of citizens when new media expose the false evaluation
ΔC_g	The additional supervision cost of government department strictly implementing	F_p	The punishment to citizens when they make false evaluation
M_g	The subsidy that government department can obtain when strictly implementing	V_p	The reward from new media when citizens make true evaluation
F_g	The punishment that government department should bear when not strictly implementing	C_{mh}	The cost that new media report after verification
C_{eh}	The cost of pharmaceutical enterprises actively participating	C_{ml}	The cost that new media report without verification
C_{el}	The cost of pharmaceutical enterprises passively participating	V_m	The information value that new media can obtain when citizens make true evaluation
M_e	The subsidy given by the government department to pharmaceutical enterprises	R_m	The pageview revenue that new media can obtain when they verify the false evaluation
D_e	The reputation loss when pharmaceutical enterprises actively participate	T_m	The new media's loss of pageview value when they report false evaluation
R_e	The additional sales revenue when pharmaceutical enterprises actively participate	F_m	The punishment that new media should bear when they report false evaluation

The replicator dynamic equation and its first derivative are

$$F(g) = dg/dt = x(E_g - \overline{E}) = g(1-g)(E_g - E_{1-g})$$
$$= g(1-g)[M_g - \Delta C_g - M_e + (1-e)F_e + (1-e)pF_g] \tag{3}$$

$$F'(g) = (1-2g)[M_g - \Delta C_g - M_e + (1-e)F_e + (1-e)pF_g] \tag{4}$$

According to the fundamental theorem of stability of differential equations, when $F(g) = 0$ and $F'(g) < 0$, the probability of government department's strategy choice is in a stable state.

Proposition 1 *When $e < e_0$ or $p > p_0$, the evolutionary stable strategy of government department is "Implement strictly". When $e > e_0$ or $p < p_0$, the evolutionary stable strategy of government department is "Not implement strictly". When $e = e_0$ or $p = p_0$, there is no evolutionary stable strategy. The thresholds are $e_0 = 1 - (M_e + \Delta C_g - M_g)/(F_e + pF_g)$ and $p_0 = [M_e + \Delta C_g - M_g - (1-e)F_e]/[(1-e)F_g]$.*

Proof Let $G(e,p) = M_g - \Delta C_g - M_e + (1-e)F_e + (1-e)pF_g$. When $G(e,p) = 0$, we can get $e_0 = 1 - (M_e +$

$\Delta C_g - M_g)/(F_e + pF_g)$ and $p_0 = [M_e + \Delta C_g - M_g - (1-e)F_e]/[(1-e)F_g]$. Take the first-order derivative of $G(e,p)$ with respect to e and p, then get $\partial G(e,p)/\partial e < 0$ and $\partial G(e,p)/\partial p > 0$. So, $G(e,p)$ is a decreasing function of e, and an increasing function of p. When $e < e_0$ or $p > p_0$, there are $G(e,p) > 0, F'(g)|_{g=1} < 0$ and $F(g)|_{g=1} = 0$, then $g = 1$ is the evolutionary stable strategy. When $e > e_0$ or $p < p_0$, there are $G(e,p) < 0$, $F'(g)|_{g=0} < 0$ and $F(g)|_{g=0} = 0$, then $g = 0$ is the evolutionary stable strategy. When $e = e_0$ or $p = p_0$, there are $G(e,p) = 0$ and $F'(g) = 0$, so there doesn't exist evolutionary stable strategy.

To sum up, the response function of the probability of government department choosing "Implement strictly" is

$$g = \begin{cases} 0 & if \quad e > e_0 \quad or \quad p < p_0 \\ [0,1] & if \quad e = e_0 \quad or \quad p = p_0 \\ 1 & if \quad e < e_0 \quad or \quad p > p_0 \end{cases} \tag{5}$$

The proposition 1 shows that in public health events, when the probability of pharmaceutical enterprises actively participating in emergency management is low or the probability of citizens making true evaluation is high, the

Table 3 The game matrix of the four-party in emergency management supervision

Pharmaceutical enterprises		Citizens			
		Evaluate truly p		Evaluate falsely $1-p$	
	New media	Report after verification m	Report without verification $1-m$	Report after verification m	Report without verification $1-m$
Government department					
Implement strictly g					
Participate actively e		$M_g - C_g - \Delta C_g - M_e$ $M_e + R_e - C_{eh}$ $V_p - C_{pt}$ $V_m - C_{mh} - V_p$	$M_g - C_g - \Delta C_g - M_e$ $M_e + R_e - C_{eh}$ $V_p - C_{pt}$ $V_m - C_{ml} - V_p$	$M_g - C_g - \Delta C_g - M_e$ $M_e + R_e - C_{eh}$ $-C_{pf} - U_p - F_p$ $R_m - C_{mh}$	$M_g - C_g - \Delta C_g - M_e$ $M_e + R_e - C_{eh} - D_e$ $-C_{pf} - F_p$ $-C_{ml} - T_m - F_m$
Participate passively $1-e$		$M_g - C_g - \Delta C_g - M_e + F_e$ $M_e - C_{el} - F_e - L_e$ $V_p - C_{pt}$ $V_m - C_{mh} - V_p$	$M_g - C_g - \Delta C_g - M_e + F_e$ $M_e - C_{el} - F_e - L_e$ $V_p - C_{pt}$ $V_m - C_{ml} - V_p$	$M_g - C_g - \Delta C_g - M_e + F_e$ $M_e - C_{el} - F_e$ $-C_{pf}$ $-C_{mh}$	$M_g - C_g - \Delta C_g - M_e + F_e$ $M_e - C_{el} - F_e$ $M_e - C_{pf}$ $-C_{ml}$
Not implement strictly $1-g$					
Participate actively e		$-C_g$ $R_e - C_{eh}$ $V_p - C_{pt}$ $V_m - C_{mh} - V_p$	$-C_g$ $R_e - C_{eh}$ $V_p - C_{pt}$ $V_m - C_{ml} - V_p$	$-C_g$ $R_e - C_{eh}$ $-C_{pf} - U_p - F_p$ $R_m - C_{mh}$	$-C_g$ $R_e - C_{eh} - D_e$ $-C_{pf} - F_p$ $-C_{ml} - T_m - F_m$
Participate passively $1-e$		$-C_g - F_g$ $-C_{el} - L_e$ $V_p - C_{pt}$ $V_m - C_{mh} - V_p$	$-C_g - F_g$ $-C_{el} - L_e$ $V_p - C_{pt}$ $V_m - C_{ml} - V_p$	$-C_g$ $-C_{el}$ $-C_{pf}$ $-C_{mh}$	$-C_g$ $-C_{el}$ $-C_{pf}$ $-C_{mh}$

probability of government department choosing "Implement strictly" will be stable at 1. Therefore, when the enthusiasm of pharmaceutical enterprises to participate in the emergency management is insufficient, the government department will play a regulatory role; when the enthusiasm of pharmaceutical enterprises is high, the government department often have the phenomenon of dereliction of duty. In addition, the citizens' true evaluation on pharmaceutical enterprises will help promote the government department to exercise the regulatory role, that is,
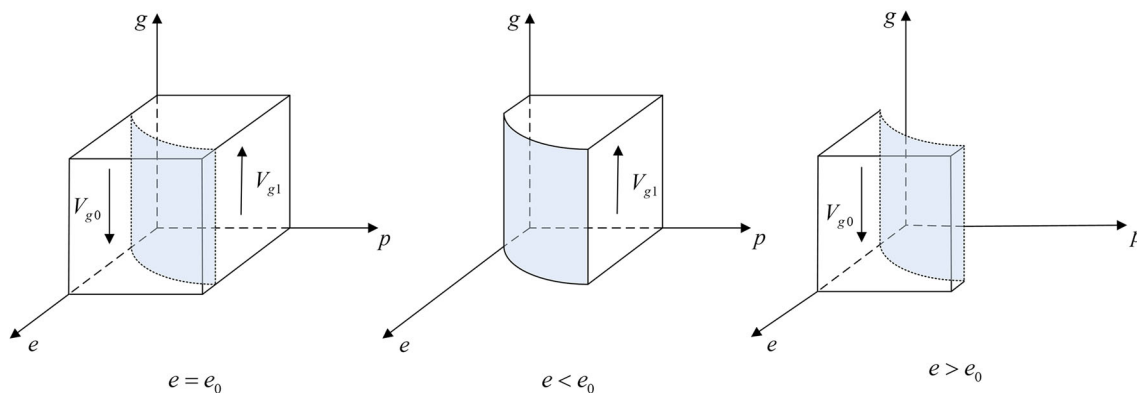

Fig. 2 The evolutionary trend of government department's strategy. In this figure, we describe the evolutionary trend of government department's strategy and the probability of government department's strategy choice changes with the probability of pharmaceutical enterprises' strategy choice

the citizens can play the supervisory role on both pharmaceutical enterprises and government department.

According to proposition 1, the evolutionary trend of government department's strategy is shown in Fig. 2.

From Fig. 2, the probability that government department chooses "Implement strictly" equals the volume V_{g1} and the probability that government department chooses "Not implement strictly" equals the volume V_{g0}.

$$V_{g1} = \int_0^1 \int_0^1 1 - \frac{M_e + \Delta C_g - M_g}{F_e + pF_g} dpdg$$
$$= 1 - \frac{M_e + \Delta C_g - M_g}{F_g} \ln \frac{F_e + F_g}{F_e}$$

$$V_{g0} = 1 - V_{g1} = \frac{M_e + \Delta C_g - M_g}{F_g} \ln \frac{F_e + F_g}{F_e}$$

Corollary 1.1 *The probability that government department chooses "Not implement strictly" is positively correlated with additional supervision cost, and negatively correlated with the punishment imposed by the superior government.*

Proof Take the first-order derivative of V_{g0} with respect to ΔC_g and F_g, and we can get

$$\frac{\partial V_{g0}}{\partial \Delta C_g} = \frac{1}{F_g} \ln \frac{F_e + F_g}{F_e} > 0$$

$$\frac{\partial V_{g0}}{\partial F_g} = -\left[\frac{M_e + \Delta C_g - M_g}{F_g^2} \ln \frac{F_e + F_g}{F_e} + \frac{M_g - \Delta C_g - M_e}{F_g(F_e + F_g)} \right] < 0$$

Corollary 1.1 indicates that the greater the additional supervision cost, the greater the probability that the government department will choose "Not implement strictly". And when the government department bears more punishment for not strictly implementing the emergency management system, the less likely it is to choose "Not implement strictly".

Corollary 1.2 *The probability that government department chooses "Implement strictly" is positively correlated with the subsidy from the superior government and the punishment to pharmaceutical enterprises and negatively correlated with the subsidy to pharmaceutical enterprises.*

Proof Take the first-order derivative of V_{g1} with respect to M_g, F_e and M_e, and we can get

$$\frac{\partial V_{g1}}{\partial M_g} = \frac{1}{F_g} \ln \frac{F_e + F_g}{F_e} > 0$$

$$\frac{\partial V_{g1}}{\partial F_e} = \frac{M_e + \Delta C_g - M_g}{F_g(F_e + F_g)} > 0$$

$$\frac{\partial V_{g1}}{\partial M_e} = -\frac{1}{F_g} \ln \frac{F_e + F_g}{F_e} < 0$$

Corollary 1.2 indicates that subsidy from the superior government can promote the government department to strictly implement the emergency management system, but the subsidy to pharmaceutical enterprises will reduce the enthusiasm of the government department to strictly implement. Besides, the greater the punishment imposed by government department on pharmaceutical enterprises, the greater the probability that government department will choose "Implement strictly".

Corollary 1.3 *When the government department doesn't strictly implement the emergency management system, if the punishment imposed by the superior government satisfies $F_g > F_{g0}$, the government department will choose "Implement strictly". But if $F_g < F_{g0}$, the government department will choose "Not implement strictly". The threshold is $F_{g0} = [M_e + \Delta C_g - M_g - (1 - e)F_e]/(1 - e)p$.*

Proof According to proposition 1, when $G(e, p) = 0$, we can get $F_{g0} = [M_e + \Delta C_g - M_g - (1 - e)F_e]/(1 - e)p$. Take the first-order derivative of $G(e, p)$ with respect to F_g, and get $\partial G(e, p)/\partial F_g > 0$. So, $G(e, p)$ is an increasing function of F_g. When $F_g > F_{g0}$, there are $G(e, p) > 0$ and $F'(g)|_{g=1} < 0$. When $F_g < F_{g0}$, there are $G(e, p) < 0$ and $F'(g)|_{g=0} < 0$.

Corollary 1.3 indicates that when the punishment F_g imposed by the superior government is greater than the threshold F_{g0}, the government department will choose "Implement strictly". When F_g is less than the threshold F_{g0}, the government department will choose "Not implement strictly". Therefore, the superior government should formulate a severe punishment mechanism to urge the government department to strictly implement the emergency management system.

4.2 Evolutionary stability analysis of pharmaceutical enterprises' strategy

The pharmaceutical enterprises' expected return of choosing "Participate actively" is

$$\begin{aligned}
E_e &= gpm(M_e - C_{eh} + R_e) + gp(1 - m)(M_e - C_{eh} + R_e) \\
&\quad + g(1 - p)m(M_e - C_{eh} + R_e) \\
&\quad + g(1 - p)(1 - m)(M_e - C_{eh} + R_e - D_e) \\
&\quad + (1 - g)pm(R_e - C_{eh}) + (1 - g)p(1 - m)(R_e - C_{eh}) \\
&\quad + (1 - g)(1 - p)m(R_e - C_{eh}) \\
&\quad + (1 - g)(1 - p)(1 - m)(R_e - C_{eh} - D_e) \\
&= R_e + gM_e - C_{eh} - (1 - p)(1 - m)D_e
\end{aligned}$$

(6)

The pharmaceutical enterprises' expected return of choosing "Participate passively" is

$$E_{1-e} = gpm(M_e - C_{el} - F_e - L_e)$$
$$+ gp(1-m)(M_e - C_{el} - F_e - L_e)$$
$$+ g(1-p)m(M_e - C_{el} - F_e)$$
$$+ g(1-p)(1-m)(M_e - C_{el} - F_e)$$
$$+ (1-g)pm(-C_{el} - L_e) \quad (7)$$
$$+ (1-g)p(1-m)(-C_{el} - L_e)$$
$$+ (1-g)(1-p)m(-C_{el})$$
$$+ (1-g)(1-p)(1-m)(-C_{el})$$
$$= gM_e - C_{el} - gF_e - pL_e$$

The replicator dynamic equation and its first derivative are

$$F(e) = de/dt = e(E_e - \overline{E}) = e(1-e)(E_e - E_{1-e})$$
$$= e(1-e)[R_e + C_{el} - C_{eh} - (1-p)(1-m)D_e$$
$$+ gF_e + pL_e] \quad (8)$$

$$F'(e) = (1-2e)[R_e + C_{el} - C_{eh} - (1-p)(1-m)D_e$$
$$+ gF_e + pL_e] \quad (9)$$

According to the fundamental theorem of stability of differential equations, when $F(e) = 0$ and $F'(e) < 0$, the probability of pharmaceutical enterprises' strategy choice is in a stable state.

Proposition 2 *When $g > g_1$, $p > p_1$ or $m > m_1$, the evolutionary stable strategy of pharmaceutical enterprises is "Participate actively". When $g < g_1$, $p < p_1$ or $m < m_1$, the evolutionary stable strategy of pharmaceutical enterprises is "Participate passively". When $g = g_1$, $p = p_1$ or $m = m_1$, there is no evolutionary stable strategy. The thresholds are $g_1 = [C_{eh} - C_{el} - R_e + (1-p)(1-m)D_e - pL_e]/F_e$, $p_1 = [C_{eh} - C_{el} - R_e + (1-m)D_e - gF_e]/[L_e + (1-m)D_e]$ and $m_1 = 1 - [R_e + C_{el} - C_{eh} + gF_e + pL_e]/(1-p)D_e$.*

Proof Let $H(g,p,m) = R_e + C_{el} - C_{eh} - (1-p)(1-m)D_e + gF_e + pL_e$. When $H(g,p,m) = 0$, we can get $g_1 = [C_{eh} - C_{el} - R_e + (1-p)(1-m)D_e - pL_e]/F_e$, $p_1 = [C_{eh} - C_{el} - R_e + (1-m)D_e - gF_e]/[L_e + (1-m)D_e]$ and $m_1 = 1 - [R_e + C_{el} - C_{eh} + gF_e + pL_e]/(1-p)D_e$. Take the first-order derivative of $H(g,p,m)$ with respect to g, p and m, and then we get $\partial H(g,p,m)/\partial g > 0$, $\partial H(g,p,m)/\partial p > 0$ and $\partial H(g,p,m)/\partial m > 0$. So, $H(g,p,m)$ is an increasing function of g, p and m. When $g > g_1$, $p > p_1$ or $m > m_1$, there are $H(g,p,m) > 0$, $F'(e)|_{e=1} < 0$ and $F(e)|_{e=1} = 0$, then $e = 1$ is the evolutionary stable strategy. When $g < g_1$, $p < p_1$ or $m < m_1$, there are $H(g,p,m) < 0$, $F'(e)|_{e=0} < 0$ and $F(e)|_{e=0} = 0$, then $e = 0$ is the evolutionary stable strategy. When $g = g_1$, $p = p_1$ or $m = m_1$, there are $H(g,p,m) = 0$ and

$F'(e) = 0$, so there doesn't exist evolutionary stable strategy.

To sum up, the response function of the probability of pharmaceutical enterprises choosing "Participate passively" is

$$e = \begin{cases} 0 & \text{if} \quad g < g_1 \quad \text{or} \quad p < p_1 \quad \text{or} \quad m < m_1 \\ [0,1] & \text{if} \quad g = g_1 \quad \text{or} \quad p = p_1 \quad \text{or} \quad m = m_1 \\ 1 & \text{if} \quad g > g_1 \quad \text{or} \quad p > p_1 \quad \text{or} \quad m > m_1 \end{cases} \quad (10)$$

The proposition 2 shows that with the probability of government department choosing "Implement strictly", the citizens choosing "Evaluate truly" and the new media choosing "Report after verification" increasing, the stability strategy of pharmaceutical enterprises will change from "Participate passively" to "Participate actively". Thus, the government department strictly implementing the emergency management helps to promote pharmaceutical enterprises to actively participate. And the citizens' true evaluation and the new media's verification can also play a supervisory role to pharmaceutical enterprises.

According to proposition 2, the evolutionary trend of pharmaceutical enterprises' strategy is shown in Fig. 3.

From Fig. 3, the probability that pharmaceutical enterprises choose "Participate actively" equals the volume V_{e1} and the probability that pharmaceutical enterprises choose "Participate passively" equals the volume V_{e0}.

$$V_{e0} = \int_0^1 \int_0^{1 - \frac{R_e + C_{el} - C_{eh} + gF_e}{D_e}} \frac{C_{eh} - C_{el} - R_e + (1-m)D_e - gF_e}{L_e + (1-m)D_e} dmde$$
$$= 1 - \frac{R_e + C_{el} - C_{eh} + gF_e}{D_e}$$
$$+ \frac{R_e + C_{el} - C_{eh} + gF_e + L_e}{D_e} \ln \frac{R_e + C_{el} - C_{eh} + gF_e + L_e}{D_e + L_e}$$

$$V_{e1} = 1 - V_{e0} = \frac{R_e + C_{el} - C_{eh} + gF_e}{D_e}$$
$$- \frac{R_e + C_{el} - C_{eh} + gF_e + L_e}{D_e} \ln \frac{R_e + C_{el} - C_{eh} + gF_e + L_e}{D_e + L_e}$$

Corollary 2.1 *The probability of pharmaceutical enterprises choosing "Participate passively" is positively correlated with the extra cost when actively participating, and negatively correlated with the additional sales revenue.*

Proof Take the first-order derivative of V_{e0} with respect to $(C_{eh} - C_{el})$ and R_e, and we can get

$$\frac{\partial V_{e0}}{\partial (C_{eh} - C_{el})} = \frac{1}{D_e} \ln \frac{D_e + L_e}{R_e + C_{el} - C_{eh} + gF_e + L_e} > 0$$
$$\frac{\partial V_{e0}}{\partial R_e} = -\frac{1}{D_e} \ln \frac{D_e + L_e}{R_e + C_{el} - C_{eh} + gF_e + L_e} < 0$$
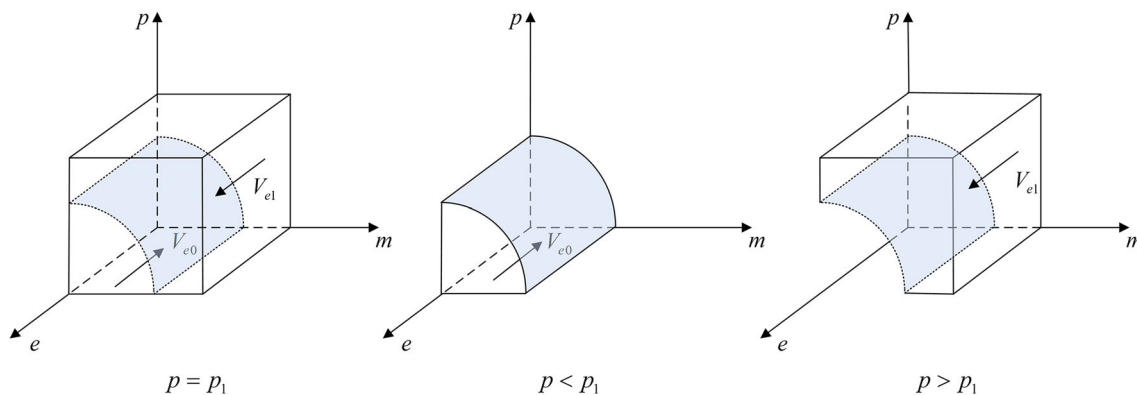
Fig. 3 The evolutionary trend of pharmaceutical enterprises' strategy. In this figure, we describe the evolutionary trend of pharmaceutical enterprises' strategy and the probability of pharmaceutical enterprises' strategy choice changes with the probability of citizens' strategy choice

Corollary 1.2 indicates that the greater the extra cost that pharmaceutical enterprises pay when actively participating in emergency management, the greater the probability that they choose "Participate passively". As pharmaceutical enterprises participate actively, the more additional sales revenue they gain, the less likely they are to choose "Participate passively".

Corollary 2.2 *The greater the probability that government department chooses "Implement strictly" and the greater the punishment that pharmaceutical enterprises should bear when they don't actively participate, the greater the probability that pharmaceutical enterprises actively participate in emergency management.*

Proof Take the first-order derivative of V_{e1} with respect to g and F_e, and we can get

$$\frac{\partial V_{e1}}{\partial g} = \frac{F_e}{D_e} \ln \frac{D_e + L_e}{R_e + C_{el} - C_{eh} + gF_e + L_e} > 0$$

$$\frac{\partial V_{e1}}{\partial F_e} = \frac{g}{D_e} \ln \frac{D_e + L_e}{R_e + C_{el} - C_{eh} + gF_e + L_e} > 0$$

Corollary 2.2 indicates that government department strictly implementing the emergency management system can improve the probability that pharmaceutical enterprises actively participate in emergency management. When pharmaceutical enterprises don't participate actively, the greater the punishment imposed by government department on them, the greater the probability that pharmaceutical enterprises will choose "Participate actively".

Corollary 2.3 *When pharmaceutical enterprises don't participate actively, if the loss caused by the citizen true evaluation satisfies $L_e > L_{e1}$, pharmaceutical enterprises will choose "Participate actively". But if $L_e < L_{e1}$, pharmaceutical enterprises will choose "Participate*

passively". The threshold is $L_{e1} = [C_{eh} - C_{el} - R_e + (1-p)(1-m)D_e - gF_e]/p$.

Proof According to proposition 2, when $H(g,p,m) = 0$, we can get $L_{e1} = [C_{eh} - C_{el} - R_e + (1-p)(1-m)D_e - gF_e]/p$. Take the first-order derivative of $H(g,p,m)$ with respect to L_e, and get $\partial H(g,p,m)/\partial L_e > 0$. So, $H(g,p,m)$ is an increasing function of L_e. When $L_e > L_{e1}$, there are $H(g,p,m) > 0$ and $F'(e)|_{e=1} < 0$. When $L_e < L_{e1}$, there are $H(g,p,m) < 0$ and $F'(e)|_{e=0} < 0$.

Corollary 2.3 indicates that when the loss L_e is greater than the threshold L_{e1}, the pharmaceutical enterprises will choose "Participate actively". When L_e is less than the threshold L_{e1}, the pharmaceutical enterprises will choose "Participate passively". Therefore, improving the impact of citizen evaluation on the loss of pharmaceutical enterprises can play a supervisory role of citizens. Government department should open the channels of citizen evaluation, so as to expand the impact of citizen evaluation on pharmaceutical enterprises.

Corollary 2.4 *When pharmaceutical enterprises participate actively, if the reputation loss caused by citizen false evaluation satisfies $D_e < D_{e1}$, pharmaceutical enterprises will choose "Participate actively". But if $D_e > D_{e1}$, pharmaceutical enterprises will choose "Participate passively". The threshold is $D_{e1} = (R_e + C_{el} - C_{eh} + gF_e + pL_e)/(1-p)(1-m)$.*

Proof According to proposition 2, when $H(g,p,m) = 0$, we can get $D_{e1} = (R_e + C_{el} - C_{eh} + gF_e + pL_e)/(1-p)(1-m)$. Take the first-order derivative of $H(g,p,m)$ with respect to D_e, and get $\partial H(g,p,m)/\partial D_e < 0$. So, $H(g,p,m)$ is a decreasing function of D_e. When $D_e < D_{e1}$, there are $H(g,p,m) > 0$ and $F'(e)|_{e=1} < 0$. When $D_e > D_{e0}$, there are $H(g,p,m) < 0$ and $F'(e)|_{e=0} < 0$.

Corollary 2.4 indicates that when the reputation loss D_e caused by citizen false evaluation is less than the threshold D_{e1}, the pharmaceutical enterprises will choose "Participate actively". When D_e is greater than the threshold D_{e1}, the pharmaceutical enterprises will choose "Participate passively". So, government department should increase the punishment for spreading rumor, strengthen the supervision to new media reports, and urge new media to verify the evaluation of citizen feedback, so as not to damage the enthusiasm of pharmaceutical enterprises to participate in emergency management.

4.3 Evolutionary stability analysis of citizens' strategy

The citizens' expected return of choosing "Evaluate truly" is

$$
\begin{aligned}
E_p &= gem(V_p - C_{pt}) + ge(1-m)(V_p - C_{pt}) \\
&\quad + g(1-e)m(V_p - C_{pt}) + g(1-e)(1-m)(V_p - C_{pt}) \\
&\quad + (1-g)em(V_p - C_{pt}) + (1-g)e(1-m)(V_p - C_{pt}) \\
&\quad + (1-g)(1-e)m(V_p - C_{pt}) \\
&\quad + (1-g)(1-e)(1-m)(V_p - C_{pt}) \\
&= V_p - C_{pt}
\end{aligned}
\tag{11}
$$

The citizens' expected return of choosing "Evaluate falsely" is

$$
\begin{aligned}
E_{1-p} &= gem(-C_{pf} - U_p - F_p) + ge(1-m)(-C_{pf} - F_p) \\
&\quad + g(1-e)m(-C_{pf}) + g(1-e)(1-m)(-C_{pf}) \\
&\quad + (1-g)em(-C_{pf} - U_p - F_p) \\
&\quad + (1-g)e(1-m)(-C_{pf} - F_p) \\
&\quad + (1-g)(1-e)m(-C_{pf}) \\
&\quad + (1-g)(1-e)(1-m)(-C_{pf}) \\
&= -C_{pf} - emU_p - eF_p
\end{aligned}
\tag{12}
$$

The replicator dynamic equation and its first derivative are

$$
\begin{aligned}
F(p) &= dp/dt = p(E_p - \overline{E}) = p(1-p)(E_p - E_{1-p}) \\
&= p(1-p)(V_p - C_{pt} + C_{pf} + emU_p + eF_p)
\end{aligned}
\tag{13}
$$

$$
F'(p) = (1-2p)(V_p - C_{pt} + C_{pf} + emU_p + eF_p)
\tag{14}
$$

According to the fundamental theorem of stability of differential equations, when $F(p) = 0$ and $F'(p) < 0$, the probability of citizens' strategy choice is in a stable state.

Proposition 3 *When $e > e_2$ or $m > m_2$, the evolutionary stable strategy of citizens is "Evaluate truly". When $e < e_2$ or $m < m_2$, the evolutionary stable strategy of citizens is "Evaluate falsely". When $e = e_2$ or $m = m_2$, there is no*

evolutionary stable strategy. The thresholds are $e_2 = (C_{pt} - C_{pf} - V_p)/(F_p + mU_p)$ and $m_2 = (C_{pt} - C_{pf} - V_p - eF_p)/eU_p$.

Proof Let $J(e,m) = V_p - C_{pt} + C_{pf} + emU_p + eF_p$. When $J(e,m) = 0$, we can get $e_2 = (C_{pt} - C_{pf} - V_p)/(F_p + mU_p)$ and $m_2 = (C_{pt} - C_{pf} - V_p - eF_p)/eU_p$. Take the first-order derivative of $J(e,m)$ with respect to e and m, then get $\partial J(e,m)/\partial e > 0$ and $\partial J(e,m)/\partial m > 0$. So, $J(e,m)$ is an increasing function of e and m. When $e > e_2$ or $m > m_2$, there are $J(e,m) > 0, F'(p)\big|_{p=1} < 0$ and $F(p)\big|_{p=1} = 0$, then $p = 1$ is the evolutionary stable strategy. When $e < e_2$ or $m < m_2$, there are $J(e,m) < 0, F'(p)\big|_{p=0} < 0$ and $F(p)\big|_{p=0} = 0$, then $p = 0$ is the evolutionary stable strategy. When $e = e_2$ or $m = m_2$, there are $J(e,m) = 0$ and $F'(p) = 0$, so there doesn't exist evolutionary stable strategy.

To sum up, the response function of the probability of citizens choosing "Evaluate truly" is

$$
p = \begin{cases}
0 & \text{if} \quad e < e_2 \quad \text{or} \quad m < m_2 \\
[0,1] & \text{if} \quad e = e_2 \quad \text{or} \quad m = m_2 \\
1 & \text{if} \quad e > e_2 \quad \text{or} \quad m > m_2
\end{cases}
\tag{15}
$$

The proposition 3 shows that with the probability of pharmaceutical enterprises actively participating increasing, the citizens' stability strategy will change from "Evaluate falsely" to "Evaluate truly". When the probability of new media choosing the "Report after verification" strategy is high, the citizens' stable strategy is "Evaluate truly". In other words, when pharmaceutical enterprises actively participate in emergency management, the citizens are more inclined to make true evaluation, and the verification by new media can improve the probability of the citizens making true evaluation.

According to proposition 3, the evolutionary trend of citizens' strategy is shown in Fig. 4.

From Fig. 4, the probability that citizens choose "Evaluate truly" equals the volume V_{p1} and the probability that citizens choose "Evaluate falsely" equals the volume V_{p0}.

$$
\begin{aligned}
V_{p0} &= \int_0^1 \int_{\frac{C_{pt} - C_{pf} - V_p}{F_p + U_p}}^{\frac{C_{pt} - C_{pf} - V_p}{F_p}} \frac{C_{pt} - C_{pf} - V_p - eF_p}{eU_p} \mathrm{d}e\mathrm{d}p \\
&= \frac{C_{pt} - C_{pf} - V_p}{U_p} \ln \frac{F_p + U_p}{F_p} \\
V_{p1} &= 1 - V_{p0} = 1 - \frac{C_{pt} - C_{pf} - V_p}{U_p} \ln \frac{F_p + U_p}{F_p}
\end{aligned}
$$

Corollary 3.1 *The probability of citizens choosing "Evaluate falsely" is negatively correlated with the cost of false evaluation and the reward from new media, and positively correlated with the cost of true evaluation.*
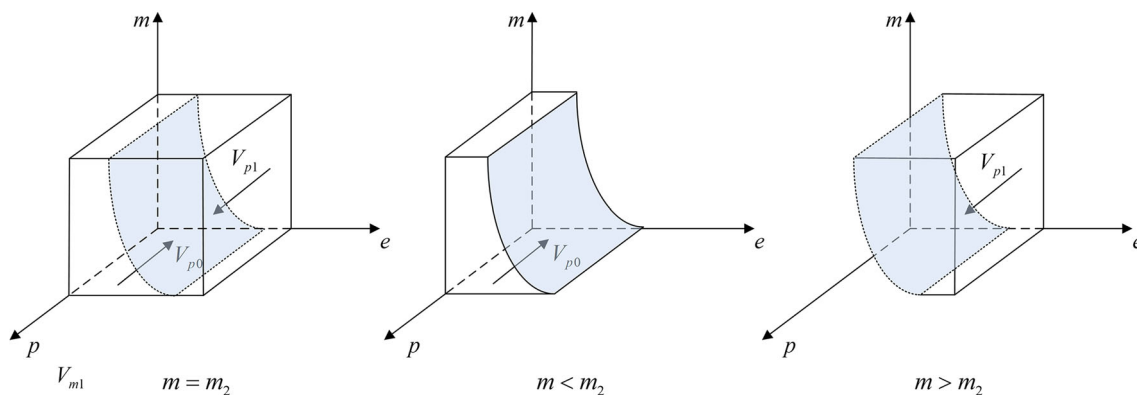
Fig. 4 The evolutionary trend of citizens' strategy. In this figure, we describe the evolutionary trend of citizens' strategy and the probability of citizens' strategy choice with the probability of new media's strategy choice

Proof Take the first-order derivative of V_{p0} with respect to C_{pf}, V_p and C_{pt}, and we can get

$$\frac{\partial V_{p0}}{\partial C_{pf}} = -\frac{1}{U_p}\ln\frac{F_p + U_p}{U_p} < 0$$

$$\frac{\partial V_{p0}}{\partial V_p} = -\frac{1}{U_p}\ln\frac{F_p + U_p}{U_p} < 0$$

$$\frac{\partial V_{p0}}{\partial C_{pt}} = \frac{1}{U_p}\ln\frac{F_p + U_p}{U_p} > 0$$

Corollary 3.1 indicates that as the cost of false evaluation decreases or the cost of true evaluation increases, the probability of the citizens choosing "Evaluate falsely" increases. The probability of "Evaluate truly" will decrease when the citizens obtain less reward for making true evaluation.

Corollary 3.2 *The probability of citizens choosing "Evaluate truly" is positively correlated with the loss of utility and punishment caused by the false evaluation.*

Proof Take the first-order derivative of V_{p1} with respect to U_p and F_p, and we can get.

$$\frac{\partial V_{p1}}{\partial U_p} = \frac{C_{pt} - C_{pf} - V_p}{U_p}\left(U_p\ln\frac{F_p + U_p}{F_p} - \frac{1}{F_p + U_p}\right) > 0$$

$$\frac{\partial V_{p1}}{\partial F_p} = \frac{C_{pt} - C_{pf} - V_p}{F_p(F_p + U_p)} > 0$$

Corollary 3.2 indicates that when the citizens make false evaluation, the greater the loss of utility, the greater the probability that citizens choose "Evaluate truly". In addition, the greater the punishment that citizens should bear

due to false evaluation, the smaller the probability of citizens choosing "Evaluate falsely".

Corollary 3.3 *When the citizens make false evaluation, if the punishment that citizens should bear satisfies $F_p > F_{p2}$, the citizens will choose "Evaluate truly". But if $F_p < F_{p2}$, the citizens will choose "Evaluate falsely". The threshold is $F_{p2} = (C_{pt} - C_{pf} - V_p - emU_p)/e$.*

Proof According to proposition 3, when $J(e,m) = 0$, we can get $F_{p2} = (C_{pt} - C_{pf} - V_p - emU_p)/e$. Take the first-order derivative of $J(e,m)$ with respect to F_p, and get $\partial J(e,m)/\partial F_p > 0$. So, $J(e,m)$ is an increasing function of F_p. When $F_p > F_{p2}$, there are $J(e,m) > 0$ and $F'(p)|_{p=1} < 0$. When $F_p < F_{p2}$, there are $J(e,m) < 0$ and $F'(p)|_{p=0} < 0$.

Corollary 3.3 indicates that when the punishment F_p that citizens should bear due to the false evaluation is greater than the threshold F_{p2}, the citizens will choose "Evaluate truly". When F_p is less than he threshold F_{p2}, the citizens will choose "Evaluate falsely". Therefore, in order to improve the probability of citizens true evaluation and give play to the citizens' supervisory role, the government department should increase the punishment to the rumor monger and rumor spreading to increase the cost of false evaluation.

4.4 Evolutionary stability analysis of new media's strategy

The new media's expected return of choosing "Report after verification" is

$$
\begin{aligned}
E_m &= gep(V_m - C_{mh} - V_p) + g(1-e)p(V_m - C_{mh} - V_p) \\
&\quad + (1-g)ep(V_m - C_{mh} - V_p) \\
&\quad + (1-g)(1-e)p(V_m - C_{mh} - V_p) \\
&\quad + ge(1-p)(R_m - C_{mh}) + g(1-e)(1-p)(-C_{mh}) \\
&\quad + (1-g)e(1-p)(R_m - C_{mh}) \\
&\quad + (1-g)(1-e)(1-p)(-C_{mh}) \\
&= -C_{mh} + pV_m - pV_p + e(1-p)R_m
\end{aligned}
$$

(16)

The new media's expected return of choosing "Report without verification" is

$$
\begin{aligned}
E_{1-m} &= gep(V_m - C_{ml} - V_p) + g(1-e)p(V_m - C_{ml} - V_p) \\
&\quad + (1-g)ep(V_m - C_{ml} - V_p) \\
&\quad + (1-g)(1-e)p(V_m - C_{ml} - V_p) \\
&\quad + ge(1-p)(-C_{ml} - T_m - F_m) \\
&\quad + g(1-e)(1-p)(-C_{ml}) \\
&\quad + (1-g)e(1-p)(-C_{ml} - T_m - F_m) \\
&\quad + (1-g)(1-e)(1-p)(-C_{ml}) \\
&= -C_{ml} + pV_m - pV_p - e(1-p)(T_m + F_m)
\end{aligned}
$$

(17)

The replicator dynamic equation and its first derivative are

$$
\begin{aligned}
F(m) &= dm/dt = m(E_m - \overline{E}) \\
&= m(1-m)[C_{ml} - C_{mh} + e(1-p)(R_m + T_m + F_m)]
\end{aligned}
$$

(18)

$$
F'(m) = (1-2m)[C_{ml} - C_{mh} + e(1-p)(R_m + T_m + F_m)]
$$

(19)

According to the fundamental theorem of stability of differential equations, when $F(m) = 0$ and $F'(m) < 0$, the probability of new media's strategy choice is in a stable state.

Proposition 4 When $e > e_3$ or $p < p_3$ the evolutionary stable strategy of new media is "Report after verification". When $e < e_3$ or $p > p_3$, the evolutionary stable strategy of new media is "Report without verification". When $e = e_3$ or $p = p_3$, there is no evolutionary stable strategy. The thresholds are $e_3 = (C_{mh} - C_{ml})/(1-p)(R_m + T_m + F_m)$ and $p_3 = 1 - (C_{mh} - C_{ml})/e(R_m + T_m + F_m)$.

Proof Let $K(e,p) = C_{ml} - C_{mh} + e(1-p)(R_m + T_m + F_m)$. When $K(e,p) = 0$, we can get $e_3 = (C_{mh} - C_{ml})/(1-p)(R_m + T_m + F_m)$ and $p_3 = 1 - (C_{mh} - C_{ml})/e(R_m + T_m + F_m)$. Take the first-order derivative of $K(e,p)$ with respect to e and p, then get $\partial K(e,p)/\partial e > 0$ and $\partial K(e,p)/\partial p < 0$. So, $K(e,p)$ is an increasing function of e, and a decreasing function of p. When $e > e_3$ or $p < p_3$, there are $K(e,p) > 0, F'(m)|_{m=1} < 0$ and $F(m)|_{m=1} = 0$,

then $m = 1$ is the evolutionary stable strategy. When $e < e_3$ or $p > p_3$, there are $K(e,p) < 0$, $F'(m)|_{m=0} < 0$ and $F(m)|_{m=0} = 0$, then $m = 0$ is the evolutionary stable strategy. When $e = e_3$ or $p = p_3$, there are $K(e,p) = 0$ and $F'(m) = 0$, so there doesn't exist evolutionary stable strategy.

To sum up, the response function of the probability of new media choosing "Report after verification" is

$$
m = \begin{cases} 0 & \text{if} \quad e < e_3 \quad \text{or} \quad p > p_3 \\ [0,1] & \text{if} \quad e = e_3 \quad \text{or} \quad p = p_3 \\ 1 & \text{if} \quad e > e_3 \quad \text{or} \quad p < p_3 \end{cases}
$$

(20)

The proposition 4 shows that with the probability that pharmaceutical enterprises actively participate in emergency management increasing, the stability strategy of new media will change from "Report without verification" to "Report after verification". When the probability that citizens' feedback true evaluation is low, the stability strategy of new media will also change from "Report without verification" to "Report after verification". So, when pharmaceutical enterprises are more active in participation, or when the probability that citizens feedback true evaluation is low, new media are more inclined to verify the evaluation from citizens to ensure the authenticity of reports.

According to proposition 4, the evolutionary trend of new media's strategy is shown in Fig. 5.

From Fig. 5, the probability that new media choose "Report after verification" equals the volume V_{m1} and the probability that new media choose "Report without verification" equals the volume V_{m0}.

$$
\begin{aligned}
V_{m1} &= \int_0^1 \int_{\frac{C_{mh}-C_{ml}}{R_m+T_m+F_m}}^1 1 - \frac{C_{mh} - C_{ml}}{e(R_m + T_m + F_m)} \, de \, dm \\
&= 1 - \frac{C_{mh} - C_{ml}}{R_m + T_m + F_m} + \frac{C_{mh} - C_{ml}}{R_m + T_m + F_m} \ln \frac{C_{mh} - C_{ml}}{R_m + T_m + F_m} \\
V_{m0} &= 1 - V_{m1} = \frac{C_{mh} - C_{ml}}{R_m + T_m + F_m} - \frac{C_{mh} - C_{ml}}{R_m + T_m + F_m} \ln \frac{C_{mh} - C_{ml}}{R_m + T_m + F_m}
\end{aligned}
$$

Corollary 4.1 The probability of new media choosing "Report after verification" is negatively correlated with the extra cost of verification, and positively correlated with the pageview revenue from verifying false evaluation.

Proof Take the first-order derivative of V_{m1} with respect to $(C_{mh} - C_{ml})$ and R_m, and we can get

$$
\frac{\partial V_{m1}}{\partial (C_{mh} - C_{ml})} = -\frac{1}{R_m + T_m + F_m} \ln \frac{R_m + T_m + F_m}{C_{mh} - C_{ml}} < 0
$$

$$
\frac{\partial V_{m1}}{\partial R_m} = \frac{C_{mh} - C_{ml}}{(R_m + T_m + F_m)^2} \ln \frac{R_m + T_m + F_m}{C_{mh} - C_{ml}} > 0
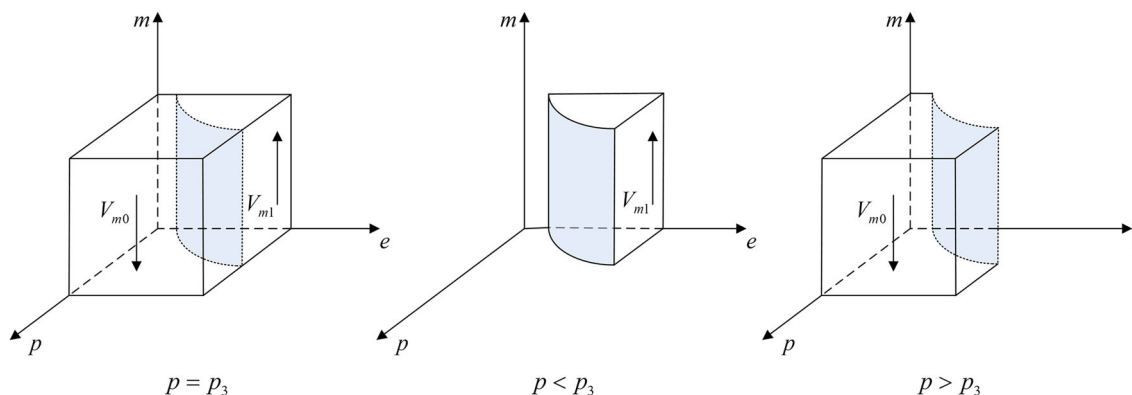$$

Fig. 5 The evolutionary trend of new media's strategy. In this figure, we describe the evolutionary trend of new media's strategy and the probability of new media's strategy choice changes with the probability of citizens' strategy choice

Corollary 4.1 indicates that reducing the cost of new media verifying citizens' evaluation or increasing the pageview revenue of verifying evaluation can improve the probability of new media choosing "Report after verification".

Corollary 4.2 *The probability of new media choosing "Report without verification" is negatively correlated with the loss of pageview value and punishment.*

Proof Take the first-order derivative of V_{m0} with respect to T_m and F_m, and we can get

$$\frac{\partial V_{m0}}{\partial T_m} = -\frac{C_{mh} - C_{ml}}{(R_m + T_m + F_m)^2} \ln \frac{R_m + T_m + F_m}{C_{mh} - C_{ml}} < 0$$

$$\frac{\partial V_{m0}}{\partial F_m} = -\frac{C_{mh} - C_{ml}}{(R_m + T_m + F_m)^2} \ln \frac{R_m + T_m + F_m}{C_{mh} - C_{ml}} < 0$$

Corollary 4.2 indicates that when the new media choose to report the citizens' evaluation without verification, if the evaluation is false, with the loss of pageview value and punishment increasing, they will be more inclined to choose "Report after verification".

Corollary 4.3 *When the new media report without verification and cause false report, if the punishment that they should bear satisfies $F_m > F_{m3}$, the new media will choose "Report after verification". But if $F_m < F_{m3}$, the new media will choose "Report without verification". The threshold is $F_{m3} = (C_{mh} - C_{ml})/e(1 - p) - R_m - T_m$.*

Proof According to proposition 4, when $K(e, p) = 0$, we can get $F_{m3} = (C_{mh} - C_{ml})/e(1 - p) - R_m - T_m$. Take the first-order derivative of $K(e, p)$ with respect to F_m, and get $\partial K(e, p)/\partial F_m > 0$. So, $K(e, p)$ is an increasing function of F_m. When $F_m > F_{m3}$, there are $K(e, p) > 0$ and $F'(m)|_{m=1} < 0$. When $F_m < F_{m3}$, there are $K(e, p) < 0$ and $F'(m)|_{m=0} < 0$.

Corollary 4.3 indicates that when the new media report without verification and cause false report, if the punishment F_m is greater than the threshold F_{m3}, the new media will choose "Report after verification". If F_m is less than F_{m3}, the new media will choose "Report without verification". Therefore, in order to exert the restrictive effect of new media on the false evaluation and curb the spread of rumor, the government department should increase the punishment to new media for rumor spreading, and avoid decrease the enthusiasm of pharmaceutical enterprises to participate in emergency management.

5 Analysis of stability equilibrium points

According to the *Lyapunov First Method*, if all the eigenvalues of the *Jacobian matrix* are negative, the equilibrium point is an evolutionary stable strategy (ESS); if the eigenvalues of the *Jacobian matrix* have at least one positive number, the equilibrium point is an unstable point; if the *Jacobian matrix*'s eigenvalues are all negative except zero, the equilibrium point is in a critical state, and the stability cannot be determined by the eigenvalue symbol (Rong et al. 2020; He et al. 2021). Therefore, we analyze the stability of 16 pure strategy Nash equilibrium points.

According to the replicator dynamic equations, the *Jacobi matrix* of the dynamic system is

$$J = \begin{bmatrix} \partial F(g)/\partial g & \partial F(g)/\partial e & \partial F(g)/\partial p & \partial F(g)/\partial m \\ \partial F(e)/\partial g & \partial F(e)/\partial e & \partial F(e)/\partial p & \partial F(e)/\partial m \\ \partial F(p)/\partial g & \partial F(p)/\partial e & \partial F(p)/\partial p & \partial F(p)/\partial m \\ \partial F(m)/\partial g & \partial F(m)/\partial e & \partial F(m)/\partial p & \partial F(m)/\partial m \end{bmatrix}$$

5.1 Stability analysis when the citizens make true evaluation

When the citizens' stable strategy is "Evaluate truly", i.e., $V_p > C_{pt} - C_{pf}$ is satisfied. Substituting the pure strategy

Table 4 Stability analysis when the citizens make true evaluation

Equilibrium point	Eigenvalues $\lambda_1, \lambda_2, \lambda_3, \lambda_4$	Sign	Stability
(0,0,1,0)	$M_g - \Delta C_g - M_e + F_e + F_g, R_e + C_{el} - C_{eh} + L_e, -(V_p - C_{pt} + C_{pf}), C_{ml} - C_{mh}$	$(\times, \times, -, -)$	Unstable
(1,0,1,0)	$-M_g + \Delta C_g + M_e - F_e - F_g, R_e + C_{el} - C_{eh} + F_e + L_e, -(V_p - C_{pt} + C_{pf}), C_{ml} - C_{mh}$	$(\times, \times, -, -)$	When condition ①is satisfied, it is ESS
(0,1,1,0)	$M_g - \Delta C_g - M_e, -R_e - C_{el} + C_{eh} - L_e, -(V_p - C_{pt} + C_{pf} + F_p), C_{ml} - C_{mh}$	$(-, \times, -, -)$	When condition ②is satisfied, it is ESS
(0,0,1,1)	$M_g - \Delta C_g - M_e + F_e + F_g, R_e + C_{el} - C_{eh} + L_e, -(V_p - C_{pt} + C_{pf}), C_{mh} - C_{ml}$	$(\times, \times, -, +)$	Unstable
(1,1,1,0)	$-M_g + \Delta C_g + M_e, -R_e - C_{el} + C_{eh} - F_e - L_e, -(V_p - C_{pt} + C_{pf} + F_p), C_{ml} - C_{mh}$	$(+, \times, -, -)$	Unstable
(1,0,1,1)	$-M_g + \Delta C_g + M_e - F_e - F_g, R_e + C_{el} - C_{eh} + F_e + L_e, -(V_p - C_{pt} + C_{pf}), C_{mh} - C_{ml}$	$(\times, \times, -, +)$	Unstable
(0,1,1,1)	$M_g - \Delta C_g - M_e, -R_e - C_{el} + C_{eh} - L_e, -(V_p - C_{pt} + C_{pf} + U_p + F_p), C_{mh} - C_{ml}$	$(-, \times, -, +)$	Unstable
(1,1,1,1)	$-M_g + \Delta C_g + M_e, -R_e - C_{el} + C_{eh} - F_e - L_e, -(V_p - C_{pt} + C_{pf} + U_p + F_p), C_{mh} - C_{ml}$	$(+, \times, -, +)$	Unstable

Note. $\times$ means that the sign is uncertain

Condition①. $\Delta C_g + M_e < M_g + F_e + F_g, R_e + F_e + L_e < C_{eh} - C_{el}$ Condition②. $R_e + L_e > C_{eh} - C_{el}, R_e + L_e > C_{eh} - C_{el}$

equilibrium points into the *Jacobi matrix*, we can get the eigenvalues, as shown in Table 4.

From Table 4, when the additional supervision cost and the subsidy to pharmaceutical enterprises are less than the subsidy to the government department as well as the punishment imposed on the pharmaceutical enterprises and the government department, and when the additional cost of pharmaceutical enterprises participating actively is greater than their additional sales revenue, the loss and punishment, the equilibrium point (1,0,1,0) is ESS. When the additional sales revenue and the loss is greater than the additional cost, the equilibrium point (0,1,1,0) is ESS.

Therefore, when pharmaceutical enterprises passively participate in the emergency management, if the government department doesn't strictly implement the emergency management system will be much punished by the superior government, the government department will strictly implement and play a regulatory role on pharmaceutical enterprises. If the loss (such as reputation decline, customer loss, etc.) caused by the citizens' true evaluation is large, the citizens can play a supervisory role on the pharmaceutical enterprises, and promote "Participate actively" to become the stable strategy of pharmaceutical enterprises.

5.2 Stability analysis when the citizens make false evaluation

When the citizens' stable strategy is "Evaluate falsely", i.e., $V_p + U_p + F_p < C_{pt} - C_{pf}$ is satisfied. Substituting the pure strategy equilibrium points into the *Jacobi matrix*, we can get the eigenvalues, as shown in Table 5.

From Table 5, when the additional cost of pharmaceutical enterprises participating actively and the loss caused by false evaluation is greater than the additional sales revenue, the equilibrium point (0,0,0,0) is ESS. When the

additional sales revenue is greater than the additional cost of pharmaceutical enterprises participating actively, the equilibrium point (1,1,0,1) is ESS.

Therefore, to avoid "Participate passively" becoming the stable strategy of pharmaceutical enterprises, the cost of active participation should be reduced and the additional sales revenue should be increased. When the cost of active participation is low and the additional sales revenue is high, the stable strategy of pharmaceutical enterprises is "Participate actively". At this time, the new media will also verify the evaluation to avoid being held accountable by pharmaceutical enterprises.

6 Simulation analysis

In order to reflect the impact of various parameters on the strategy choices of the government department, pharmaceutical enterprises, citizens and new media in public health events emergency management, we use *Matlab 2020b* to conduct the simulation analysis.

When the government department strictly implements the emergency management system, the additional supervision cost is $\Delta C_g = 4.5$, the subsidy from the superior government is $M_g = 5.0$, the subsidy to pharmaceutical enterprises is $M_e = 2.0$, the punishment imposed on pharmaceutical enterprises is $M_e = 2.0$, and When the government department doesn't strictly implement, the punishment that it should bear is $F_g = 4.0$. When the pharmaceutical enterprises actively participate in the emergency management, the additional sales revenue is $R_e = 2.5$, the additional cost is $\Delta C_e = 4.0$. When the citizens make true evaluation, the reward that they obtain from new media is $V_p = 1.0$ and the cost is $C_{pt} = 2.5$. If the pharmaceutical enterprises passively participate in the

Table 5 Stability analysis when the citizens make false evaluation

Equilibrium point	Eigenvalues $\lambda_1, \lambda_2, \lambda_3, \lambda_4$	Sign	Stability
(0,0,0,0)	$M_g - \Delta C_g - M_e + F_e, R_e + C_{el} - C_{eh} - D_e,$ $V_p - C_{pt} + C_{pf}, C_{ml} - C_{mh}$	$(-, \times, -, -)$	When condition ③ is satisfied, it is ESS
(1,0,0,0)	$-(M_g - \Delta C_g - M_e + F_e), R_e + C_{el} - C_{eh} - D_e + F_e, V_p - C_{pt} + C_{pf}, C_{ml} - C_{mh}$	$(+, \times, -, -)$	Unstable
(0,1,0,0)	$M_g - \Delta C_g - M_e, -R_e - C_{el} + C_{eh} + D_e,$ $V_p - C_{pt} + C_{pf} + F_p, C_{ml} - C_{mh} + R_m + T_m + F_m$	$(-, \times, -, +)$	Unstable
(0,0,0,1)	$M_g - \Delta C_g - M_e + F_e, R_e + C_{el} - C_{eh},$ $V_p - C_{pt} + C_{pf}, C_{mh} - C_{ml}$	$(-, \times, -, +)$	Unstable
(1,1,0,0)	$-M_g + \Delta C_g + M_e, -R_e - C_{el} + C_{eh} + D_e - F_e, V_p - C_{pt} + C_{pf} + F_p, C_{ml} - C_{mh} + R_m + T_m + F_m$	$(+, \times, -, +)$	Unstable
(1,0,0,1)	$-M_g + \Delta C_g + M_e - F_e, R_e + C_{el} - C_{eh} + F_e,$ $V_p - C_{pt} + C_{pf}, C_{mh} - C_{ml}$	$(+, \times, -, +)$	Unstable
(0,1,0,1)	$M_g - \Delta C_g - M_e, -R_e - C_{el} + C_{eh},$ $V_p - C_{pt} + C_{pf} + U_p + F_p, -C_{ml} + C_{mh} - R_m - T_m - F_m$	$(-, \times, -, -)$	When condition ④ is satisfied, it is ESS
(1,1,0,1)	$-M_g + \Delta C_g + M_e, -C_{ml} + C_{mh} - R_m - T_m - F_m, V_p - C_{pt} + C_{pf} + U_p + F_p, -C_{ml} + C_{mh} - R_m - T_m - F_m$	$(+, \times, -, -)$	Unstable

Note. × means that the sign is uncertain

Condition③. $C_{eh} - C_{el} + D_e > R_e$ Condition④. $R_e > C_{eh} - C_{el}$ $R_e > C_{eh} - C_{el}$

---

emergency management, the true evaluation will bring them the loss $L_e = 3.0$. When the citizens make false evaluation, the cost is $C_{pf} = 0.5$, and they will bear the punishment $F_p = 1.0$. When new media report after verification, the additional cost is $\Delta C_m = 2.0$, the pageview revenue is $R_m = 2.5$ and the utility loss of citizens is $U_p = 1.0$. When new media report the false evaluation, the pharmaceutical enterprises' reputation loss is $D_e = 2.0$, the new media's loss of pageview value is $T_m = 2.5$ and the punishment that new media should bear is $F_m = 3.0$.

6.1 The influence of the probability that the new media report after verification

The probability that the new media report after verification is $m = \{0.0, 0.2, 0.5\}$. The strategy evolution process and result of the government department, pharmaceutical enterprises and citizens are shown in Fig. 6.

From Fig. 6, when the probability that new media report after verification is low, the probability that the citizens make false evaluation is high, which will decrease the enthusiasm of pharmaceutical enterprises to participate in emergency management, and the government department will choose to strictly implement the emergency management system to supervise the behavior of pharmaceutical enterprises. With the increase of the probability that new media report after verification, the citizens' stability strategy is changed to "Evaluate truly", and the pharmaceutical enterprises' stability strategy is changed to "Participate actively". At this time, the government department will choose the strategy of "Not implement strictly".

6.2 The influence of the citizen participation

The probability that citizens make true evaluation is $p = \{0.2, 0.4, 0.8\}$. The strategy evolution process and result of the government department, pharmaceutical enterprises and new media are shown in Fig. 7.

From Fig. 7, when the citizens tend to make false evaluation, the stable strategy of new media is "Report after verification", and the strategy choice of pharmaceutical enterprises is constantly adjusted with the strategy choice of government department. With the increase of the probability that the citizens make true evaluation, the stability strategy of pharmaceutical enterprises is "Participate actively". At this time, the citizens play the supervisory role for pharmaceutical enterprises.

When the citizens make false evaluation, the pharmaceutical enterprises' reputation loss is $D_e = 0.5$. When the citizens make true evaluation, if pharmaceutical enterprises passively participate in the emergency management, the pharmaceutical enterprises' loss is $L_e = \{0.5, 1.0, 3.0\}$.
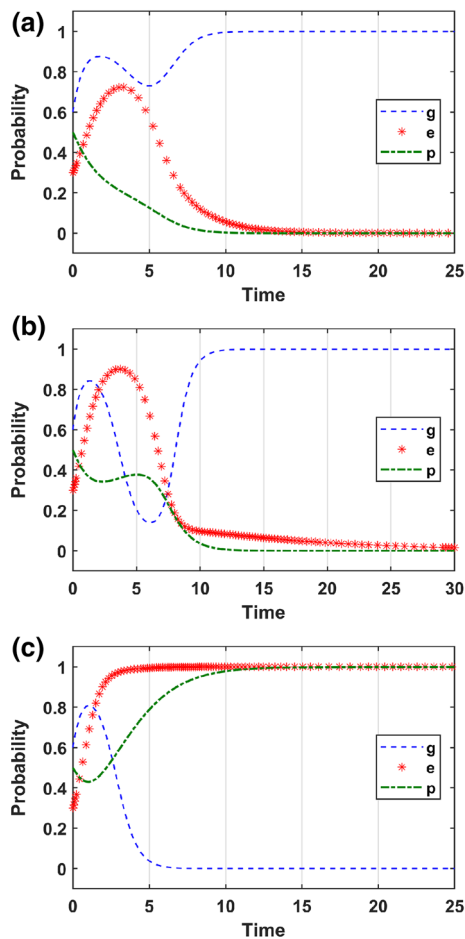
Fig. 6 The influence of the probability that the new media report after verification. In this figure, we describe that the strategy evolutionary trend of government department, pharmaceutical enterprises and citizens changes with the probability of new media's strategy choice
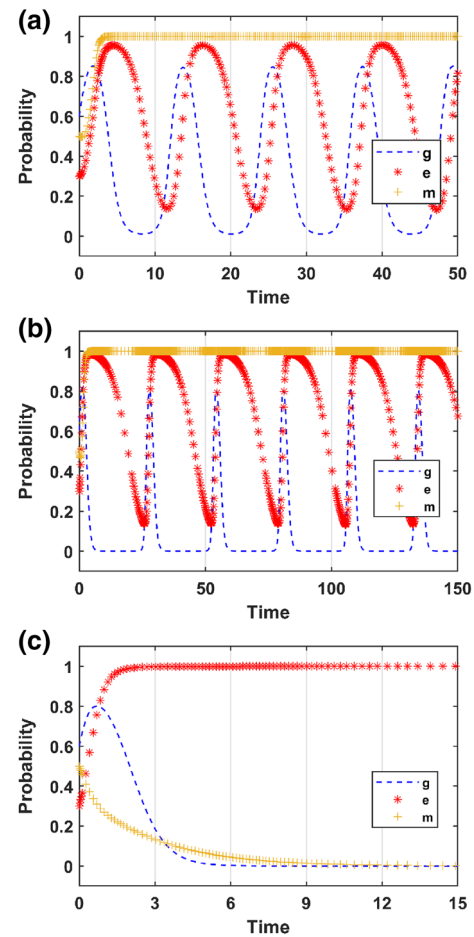

Fig. 7 The influence of the probability that citizens make true evaluation. In this figure, we describe that the strategy evolutionary trend of government department, pharmaceutical enterprises and new media changes with the probability of citizens' strategy choice

The strategy evolution process and result of the government department, pharmaceutical enterprises, citizens and new media are shown in Fig. 8.

From Fig. 8, when pharmaceutical enterprises passively participate in emergency management, with the loss caused by the true evaluation of the citizens increasing, the strategy choice of pharmaceutical enterprises changes from instability to "Participate actively", and the strategy choice of the citizens also changes from instability to "Evaluate truly". In other words, when the true evaluation has a great impact on the pharmaceutical enterprises, the citizens will be more inclined to play their own supervisory role.

When the pharmaceutical enterprises passively participate in the emergency management, if the citizens make true evaluation, the loss of pharmaceutical enterprises is $L_e = 0.5$. When the pharmaceutical enterprises actively participate in the emergency management, if the citizens

make false evaluation, the pharmaceutical enterprises' reputation loss is $D_e = \{0.0, 0.5, 1.0\}$. The strategy evolution process and result of the government department, pharmaceutical enterprises, citizens and new media are shown in Fig. 9.

From Fig. 9, when pharmaceutical enterprises actively participate in emergency management, with the reputation loss caused by false evaluation increasing, the amplitude of the probability of pharmaceutical enterprises' strategy choice will increase. At this time, the strategy choice of pharmaceutical enterprises will fluctuate with the adjustment of the strategy choice of government department. In addition, when the citizens' false evaluation causes more reputation loss to pharmaceutical enterprises, the government department needs to improve the probability of "Implement strictly" in order to ensure pharmaceutical enterprises actively participate in emergency management.
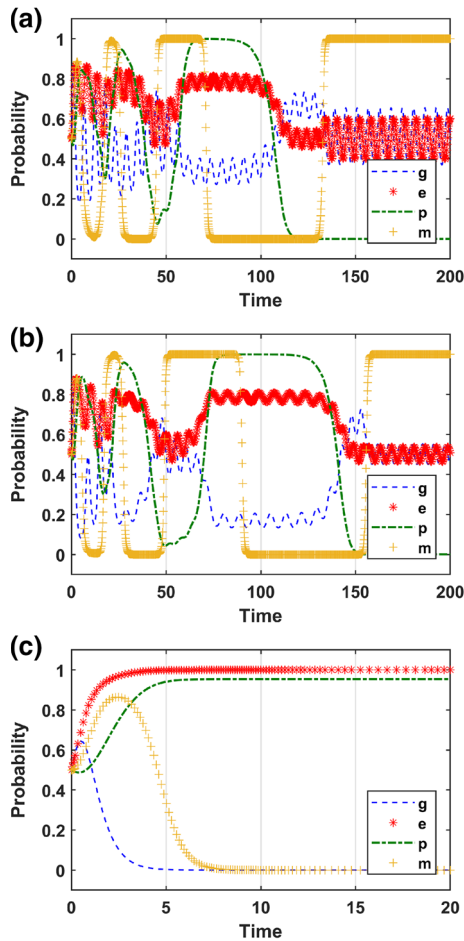
Fig. 8 The influence of the pharmaceutical enterprises' loss. In this figure, we describe how the strategy evolutionary trend of government department, pharmaceutical enterprises, citizens and new media changes with the pharmaceutical enterprises' loss increasing

Fig. 9 The influence of the pharmaceutical enterprises' reputation loss. In this figure, we describe how the strategy evolutionary trend of government department, pharmaceutical enterprises, citizens and new media changes with the pharmaceutical enterprises' reputation loss increasing

6.3 The influence of the punishment

The probability that new media report after verification is $m = 0.5$. When the government department doesn't implement strictly, the punishment is $F_g = \{0.0, 2.5, 4.0\}$. When the pharmaceutical enterprises passively participate, the punishment is $F_e = \{0.0, 2.0, 3.0\}$. When the citizens make false evaluation, the punishment is $F_p = \{0.0, 0.4, 1.0\}$. The strategy evolution process and result of the government department, pharmaceutical enterprises, and citizens are shown in Fig. 10.

From Fig. 10, when the government department doesn't strictly implement the emergency system, pharmaceutical enterprises passively participate in the emergency management, and citizens make false evaluation, if there is no punishment for them, the evolutionary stable equilibrium point is (0,0,0). With the increase of punishment when government department doesn't strictly implement, pharmaceutical enterprises passively participate, and the
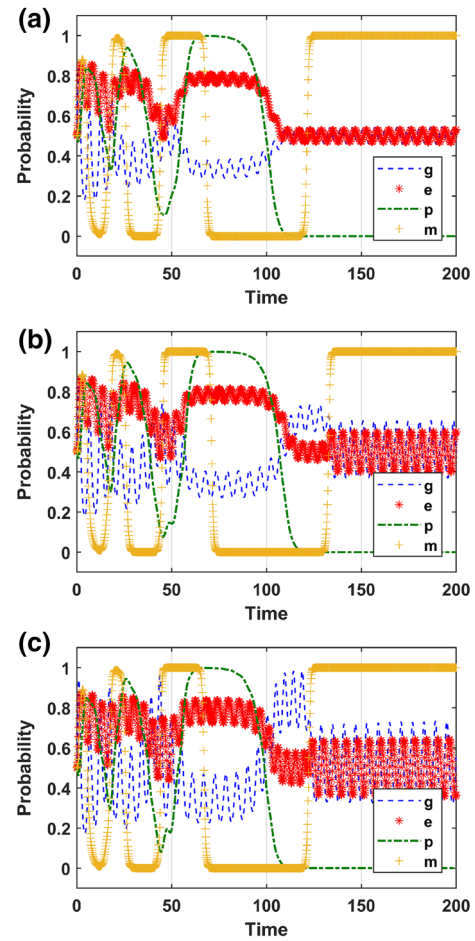
citizens make false evaluation, the equilibrium point evolves to (1,0,0), and then to (0,1,1). As a result, the punishment has a restrictive effect on the strategy choices of government department, pharmaceutical enterprises and the citizens.

7 Discussion

In this paper, we construct an evolutionary game model involving four players, analyze the evolutionary stability and solve the stable equilibrium points using the *Lyapunov first method*. In addition, we conduct the simulation analysis with *Matlab 2020b*. Then we can get the following discussion.

First of all, when the probability of pharmaceutical enterprises actively participating in emergency management is low or the probability of citizens making true evaluation is high, the stable strategy of government
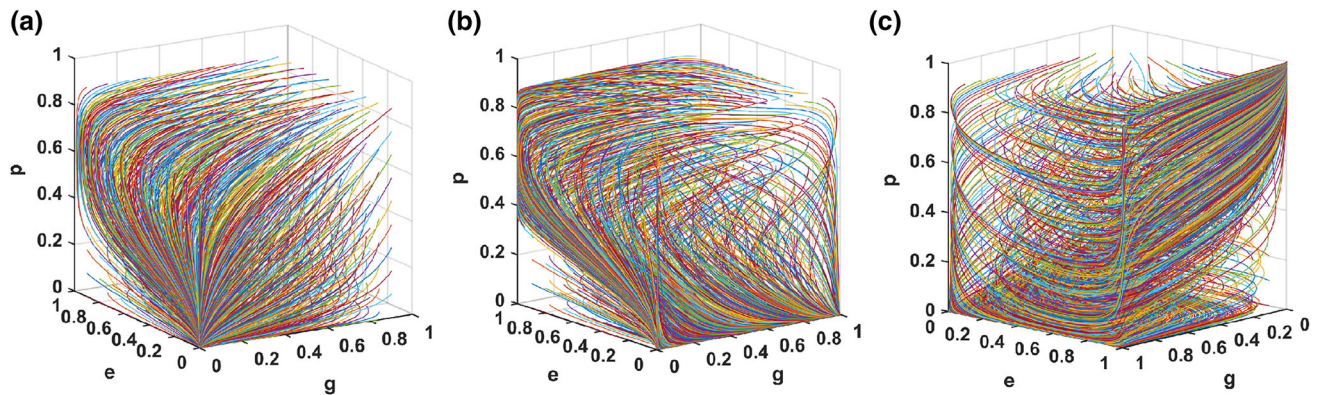
Fig. 10 The influence of the punishment. In this figure, we describe how the strategy evolutionary trend of government department, pharmaceutical enterprises and citizens changes with the punishment increasing

department is to strictly implement the emergency management system.

Secondly, with the probability of government department strictly implementing the emergency management system, the probability of citizens making true evaluation and the probability of new media reporting after verification increasing, the probability that pharmaceutical enterprises choose to actively participate in emergency management will increase.

Thirdly, when the probability of pharmaceutical enterprises actively participating in emergency management increases, the citizens' stable strategy changes from false evaluation to true evaluation. When the probability of new media reporting after verification is high, the citizens' stable strategy is true evaluation.

What's more, as the probability of pharmaceutical enterprises actively participating in emergency management increases, the probability of new media reporting after verification increases. When the probability of citizens making true evaluation is low, the stable strategy of new media is to report after verification.

8 Conclusions

From the discussion, we can reach the following conclusions.

Firstly, when pharmaceutical enterprises are less active in participating in emergency management, government department will play a regulatory role on them. In addition, citizen participation in emergency management through true evaluation can play the supervisory role on government department.

Secondly, citizens' true evaluation on pharmaceutical enterprises can exert the supervision role of citizens, but the false evaluation will decrease the enthusiasm of pharmaceutical enterprises to participate in emergency

management. So, government department should formulate policies including rewards and punishment to encourage the citizens to make true evaluation and restrict them to make false evaluation.

Thirdly, when pharmaceutical enterprises actively participate in emergency management, the citizens are more inclined to make true evaluation. Besides, new media's verification can improve the probability of citizens making true evaluation and the probability of pharmaceutical enterprises actively participating.

In addition, the greater the punishment imposed on new media for false report, the greater the probability of new media reporting after verification. Therefore, when new media release false report, government department should strengthen the punishment to improve the probability of new media report after verification.

This paper constructs a four-party evolutionary game model. Its main advantage is that the model can take the strategy choices of government department, pharmaceutical enterprises, new media and citizen into account at the same time, and on the basis, we can study the interaction between different agents' strategy choices through model analysis. However, the game model is one-stage under the condition of bounded rationality and without considering the game sequence. In reality, the sequence in which each participant makes strategy choices will also affect the results of the game. Therefore, in the future research, we will build a multi-stage, repeated and dynamic game model with multi-agent participation under the condition of incomplete information. Furthermore, we will combine real-time cases for further research.

Author contributions BL (first author) wrote the manuscript and made the simulation analysis; LZ (corresponding author) designed the model and revised the manuscript.

Data availability All the data is available and within the manuscript, no supplement materials data.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This work does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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