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ORIGINAL RESEARCH

The Early Warning Mechanism of Public Health Emergencies Through Whistleblowing: A Perspective Based on Considering the Uncertainty of Risk Perception

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Purpose: During the early warning period of public health emergencies, the information released by whistleblowers on the risk posed by the given event can reduce uncertainty in the public's risk perception and help governments take timely actions to contain the large-scale dissemination of risk. The purpose of this study is to give full play to whistleblowers and draw attention to the risk events, forming a pluralistic model of the risk governance during the early warning period of public health emergencies.

Methods: We construct an evolutionary game model of the early warning of public health emergencies through whistleblowing that involves the government, whistleblowers, and the public, discussing the mechanism of interaction between these subjects under the uncertainty of risk perception. Furthermore, we use numerical simulations to analyze the influence of changes in the relevant parameters on the evolutionary trajectory of the subjects' behaviors.

Results: The results of the research are obtained by numerical simulation of the evolutionary game model. The results show that the public's cooperation with the government encourages the latter to take a positive guidance strategy. Increasing the reward for whistleblowers within an acceptable cost, strengthening the propaganda of the mechanism and the higher level of risk perception of the government and whistleblowers will promote whistleblowers' vocalization actively. When the government's reward for whistleblowers is lower, the whistleblowers choose negative vocalization with the improvement of the public's risk perception. If there is no mandatory guidance from the government at this point, the public is prone to passively cooperating with the government owing to a lack of risk-related information.

Conclusion: Establishing an early warning mechanism through whistleblowing is important for containing risk in the early warning period of public health emergencies. Building the whistleblowing mechanism in daily work can improve the effectiveness of the mechanism and enhance the public's risk perception better when the public health emergencies arise.

Keywords: public health emergencies, early warning through whistleblowing, risk prevention, uncertainty in perception, evolutionary game

Introduction

Such public health emergencies as SARS, Influenza A, MERS, and Ebola virus disease have broken out frequently in the 21st century. They pose a significant threat to public health and safety and present a daunting challenge to national governance and social resilience.[1–3] COVID-19, which emerged in late 2019 and spread rapidly across the globe, has been recognized as a "Public Health Emergency of International Concern" by the World Health Organization.[4–6] In response to the sudden public health crisis, the Chinese government made quick decisions and enacted measures, including emergency lockdowns, the establishment of makeshift hospitals, the timely dissemination of information

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about the pandemic, instructions to the public to take effective preventive measures, and mandatory public vaccination. These measures significantly helped contain the spread of the pandemic in China.[7,8] The government's attitude during the early warning period of a public health crisis and the public's behavioral choices when exposed to risk are important to the development of the crisis for the future. Both play a decisive role in mitigating losses and preventing crises from evolving. Uncertainty, vagueness, dynamics, complexity, and derivatization are common features of public health emergencies. People do not have access to a sufficient amount of information during the early warning period, where which makes it difficult for them to accurately assess the risk at hand and adopt appropriate preventive actions. This can have far-reaching negative impacts on social stability, the ecological environment, and citizens' health.[9] In addition to relying on accurate surveillance-based information, risk assessment for public health emergencies should consider the basic pattern of development of an epidemic under specific conditions. In particular, the exchange of knowledge among subjects while giving full play to the technical advantages offered by experts is important. Whistleblowers, such as frontline healthcare staff, can help improve the public perception of risk and encourage people to take preventive measures. In the early stage of the COVID-19 pandemic, some frontline medical staff took the initiative to speak out based on their experiences and acted as whistleblowers. However, they were muzzled and subsequently reprimanded by public security authorities. Given the uncertainty of risk perception, the government continues to ignore important warnings by whistleblowers, and this significantly increases the likelihood of exposing the public to risks, enhances the risk of large-scale outbreaks, and poses a significant barrier to the subsequent prevention and control of the emergency.

The measures of containment implemented during the early warning period of the risk posed by a public health emergency can help control the spread of the risk. The large-scale global outbreak of COVID-19, however, shows that we have not done a good job of alerting the public of the risks posed by such events. Neither the government nor the public have been sufficiently sensitive to the warnings, and have lacked the capacity to respond to the situation.[10] People's perceptions of risk in the early warning period of public health emergencies are often more uncertain and vague compared with other stages of risk management. People's behavioral choices are not only constrained by cost, but are also subject to such factors as the efficient acquisition of information and the individual level of risk perception. Together, these factors determine whether people engage in preventive behaviors. An effective whistleblowing mechanism that considers the views of clinicians and other frontline medical staff during the early warning period of public health emergencies is thus needed. This can help enhance the public's perception of risk and help control the crisis in a timely manner.

Literature Review

Protective System for Whistleblowers and Early Warning Mechanism Through Whistleblowing

Social media has emerged as an important source of information for the public in recent years.[11,12] Researchers in risk management have claimed that social media influences people's perception of risk and in turn affect their behavior.[13,14] Warnings by whistleblowers also have implications for the public's perception of risk and subsequent behaviors. Whistleblowers are the employees of an organization who expose the violations of law and regulations by their employer that damage the public interest, and attract the attention of the relevant authorities and the public.[15] Whistleblowing is closely linked to public safety and social interests, and can enhance the effectiveness of risk management.[16] The early warning mechanism through whistleblowing can function properly only when the whistleblower's personal safety and basic rights are protected. Whistleblowers are in fact often in a disadvantaged position owing to internal pressures imposed on them by their employers even though their exposure of information is conducive to social benefit and protecting the public interest.[17,18] In light of the differences in the culture and dynamics of different countries, Chordiya et al quantitatively analyzed the practical pathways of establishing a "whistleblower protection system" from the perspectives of ethics, leadership behavior, institutional norms, and legislative protection.[19] Some scholars have studied the factors that influence whistleblowing behavior. Individual ability, support from coworkers, public expectations, economic rewards, and freedom from reprisals have significant positive effects on whistleblowing, while gender, age, years of work, and job characteristics have varying effects on whether employees make the decision to report

wrongdoing.[20,21] Whistleblowers are encouraged to come forward in a variety of ways but their willingness to report wrongdoing is complicated.[22] Before deciding to act, whistleblowers may weigh such factors as the cost of disclosure, its potential benefits, and the seriousness of the offending behavior in question.[23,24]

Risk Perception and Preventive Behaviors

Risk perception is an individual's subjective judgment of the risk posed by an event—in essence their psychological cognition of the risk or crisis.[25] A large body of research has investigated the factors that influence risk perception,[26–28] and the relationship between risk perception and preventive behavior. Preventive behavior is known to be influenced by risk perception. Research in medicine suggests that preventative measures taken by members of the public can significantly contain the spread of infectious diseases.[29] The higher the level of the public's risk perception of a disease is, the more likely is it to take the relevant actions to curtail its spread, thereby protecting vulnerable groups as well as society at large.[30] Li et al found that in the case of an uncertainty in it, enhancing risk perception can prompt people to assume preventive behaviors, which in turn can increase risk perception through an analysis of the facts of China and the United States.[31] Kim et al confirmed that families with higher levels of risk perception of H1N1 influenza were more likely to adopt preventive behaviors, even after controlling for ethnicity, family structure, and personal experience. In addition to investigating the direct impact of risk perception on preventive behavior, researchers have regarded the risk perception as a mediating variable of the preventive behavior in recent years.[9,32] Zancu et al used Zimbabwe as an example to explore the mediating role of risk perception between time and preventive behavior.[33] Karasneh et al evaluated how the media reshapes the risk perception of pharmacists such that they take more rational preventive actions during a pandemic.[34] In addition to risk perception, trust in the sources of information is a crucial factor that enables the public to take protective actions.[35,36] People's risk perception changes with the acquisition of information, and healthcare professionals are perceived to be the most trustworthy in case of the availability of a large amount of information,[37,38] and healthcare workers should focus on improving their perceived self-efficacy.[39] A study by Okuhara et al also showed that the risk-related information conveyed by physicians is more likely to cause the public to voluntarily take self-protective actions.[40] Moreover, the degree of trust between the government and society has differential effects on people's risk perception as well as their subsequent behaviors and decisions.[41–44]

Preventive Behaviors, and Benefits of Prevention and Control

Practices in different countries have shown that taking the necessary precautions during a pandemic has a positive effect on checking the spread of the disease. While some preventative measures inconvenience people's lives, engaging in such behaviors in a timely manner is an effective means of minimizing loss from a cost–benefit perspective.[45] Scholars have constructed models to simulate the development of epidemics in different scenarios. Yu et al constructed the SEIR-AQ model to predict the developmental trend of an epidemic under different measures of prevention and control.[46] Samanlioglu et al devised a hesitant fuzzy analytic hierarchy process (AHP) model to assess different policies of intervention adopted by countries in an attempt to contain the spread of COVID-19.[47] Jia et al used system dynamics to analyze the role of material supply, the dissemination of public opinion, risk perception, and policy-based intervention in improving the effectiveness of epidemic prevention and control.[48] Yin et al constructed a local equilibrium model to analyze the impact of the government's interventions on the social economy under infectious diseases with different intensities.[49] Roberts et al designed a set of sequential mediation models to find the key factors that influence college students' behaviors and emphasized how individual self-protection can greatly reduce the rate of infection in the population.[50]

According to the above literature review, whistleblowers' active vocalization can make the public know more details about the risk posed by an event, increase its risk perception, and prompt the relevant departments to take appropriate measures. Most research on whistleblowers has focused on businesses and few studies have considered them in the context of public health emergencies. This study uses evolutionary game theory to explore the process of dynamic decision-making involving local governments (hereinafter referred to as "the government"), whistleblowers, and the public during the early warning period in case of public health emergencies in light of the uncertainty of the subjects' risk perception. The degree of rationality and the behavioral choices of agents in the game constantly change with changes in

the situation.[51] The key is to analyze the process of behavioral interactions during the learning mechanisms of subjects and their behavioral choices in dynamic situations.[52,53] We focus here on ways to better prevent and control risk in the early warning period in case of public health emergencies, and to provide suggestions for the government to improve the effectiveness of its response to public health emergencies.

Evolutionary Game Model of the Early Warning of Public Health Emergencies Through Whistleblowing

Problem Description

The judgments and choices of decision-makers are influenced by their perceptions of risk, responsibility, cost, and value. Public health emergencies are special in that different subjects have varying risk perceptions of them. As new features of the risk posed by such an emergency emerge, individuals are often insensitive to them and thus are unable to evaluate the severity of the event. Whistleblowers referring to frontline medical staff, experts in infectious diseases and virology, and other medical workers with a professional background, often capture first-hand data on timeliness and authenticity. They are vital in the early warning period of public health emergencies as they play a leading role in detecting the signs of danger in a timely manner, resolving the asymmetry of information, sounding the alarm for society at large, and urging the government to discharge its responsibility of crisis management. The whistleblowers' behaviors are mainly affected by the government. If the government encourages them to speak out, it can build channels for whistleblowers to make a voice and provide them with certain rewards for their actions. When the government discourages whistleblowers, the latter bear more cost of whistleblowing and are likely to be less forthcoming. The government, as the leader in the handling of public health emergencies, should consider the risk-related information disclosed by whistleblowers and actively guide to mitigate and, if possible, eliminate the risk posed by the event. However, "maintaining stability" is the top priority of the government in practice. To prevent social panic caused by an overreaction to the event, the government often ignores whistleblowers and even holds them to account for their actions. As a direct undertaker of the risk posed by the emergency, the public has a right to knowledge that can enhance its level of risk perception through information disclosed by whistleblowers. On the one hand, the public can cooperate with the government and follow the whistleblowers' advice; on the other hand, it can choose to ignore the risk-related information. The behavioral choices of the government, whistleblowers, and the public are closely related to the cost and the potential benefits of their actions, and changes in the subjects' behaviors are closely linked to the effects of risk prevention and the degree of loss reduction. In summary, the government, whistleblowers, and the public are the main subjects of the model in our study. We use the method of the evolutionary game to explore how to achieve effective game and behavioral coordination among these subjects in order to minimize the risky hazards of public health emergencies during the early warning period. On this basis, we construct an evolutionary game model of the early warning of public health emergencies through whistleblowing. The relationships between the subjects involved in this are shown in Figure 1. We propose certain hypotheses and explain the parameters of our model to clarify the mechanism of dynamic decision-making and cooperation involving the government, whistleblowers, and the public during the early warning period of public health emergencies. The description of the model parameters is shown in Table 1.

Assumptions and Parameter Settings

Assumption 1: The government, whistleblowers, and the public are all bound to rationality in the evolutionary game model of the early warning of public health emergencies through whistleblowing. The subjects in the game model have some informational asymmetry and uncertainty of perception. The strategy choices of the government, whistleblowers, and the public all seek to maximize their own interests.

Assumption 2: Depending on the situation and its self-interest, the government may choose either positive guidance (guiding whistleblowers to make a voice and the public to take preventive measures) or a negative guidance strategy with probabilities x and 1-x, respectively. Whistleblowers tend to have a higher level of risk perception than the government and the general public due to the specificity of their profession. They may adopt one of two strategies when perceiving the risk posed by an event: positive vocalization (disclosing the risk-related information posed by the event) or negative vocalization. The probability that whistleblowers choose the positive strategy is y. If they are unwilling to bear the cost

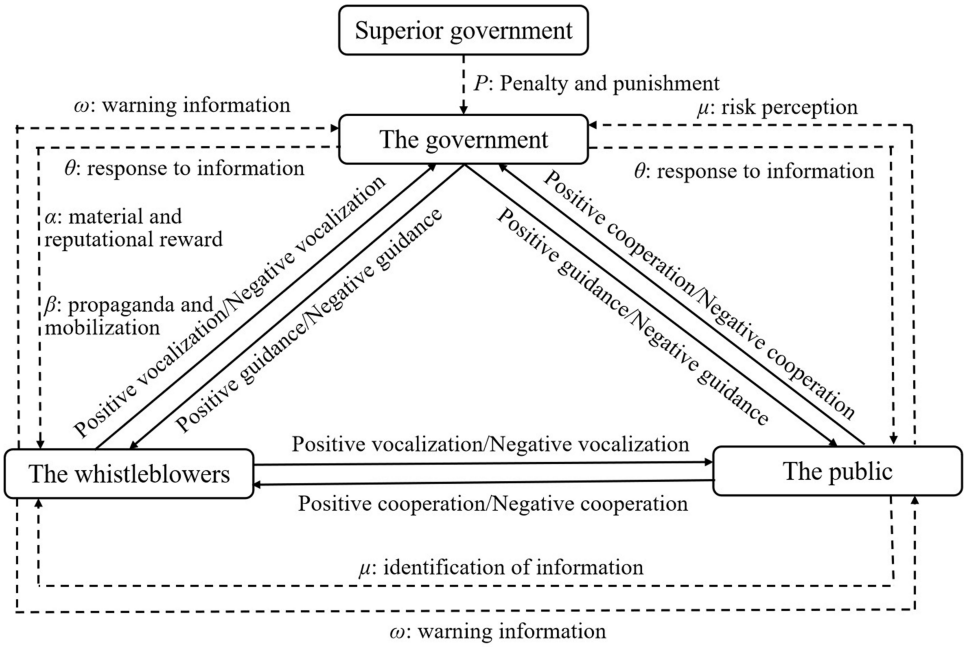

Figure 1 The evolutionary game model of the early warning of public health emergencies through whistleblowing.

and risk of making a voice, the probability that they choose to adopt a negative strategy, to not making a voice, is 1-y. The public also has a choice between the strategies of positively or negatively cooperating with the government in preventing and controlling risk, with probabilities z and 1-z, respectively.

Table 1 Description of the Model Parameters

Parameter	Definition	Ranges
C_1	The cost of necessary emergency measures paid by the government.	$C_1 \geq 0$
C_2	The cost to whistleblowers for making a voice.	$C_2 \geq 0$
C_3	The cost of personal protection and the loss due to the inconvenience of living and working when the public chooses a positive cooperation strategy.	$C_3 \geq 0$
L_1	The economic and social losses suffered by the government when all three subjects adopt negative strategies.	$L_1 \geq 0$
L_2	The economic and security losses suffered by the whistleblowers when all three subjects adopt negative strategies.	$L_2 \geq 0$
L_3	The economic and security losses suffered by the public when all three subjects adopt negative strategies.	$L_3 \geq 0$
K_1	The maximum amount of reward that the government gives to whistleblowers for making a voice under positive guidance from the government.	$K_1 \geq 0$
K_2	The cost of building the mechanism of early warning through whistleblowing borne by the government.	$K_2 \geq 0$
K_3	The cost of the response to warnings when both the government and whistleblowers choose to positive strategy.	$K_3 \geq 0$
G	The gains obtained by the government when all three subjects choose the positive strategy.	$G \geq 0$
P	The superior government's penalties for the local government for ignoring the whistleblower's warnings, where this has led to the large-scale spread of risk.	$P \geq 0$
R_1	The upper bound on the material rewards that whistleblowers receive when both they and the government adopt the positive strategy.	$R_1 \geq 0$
R_2	The upper bound on the reputational reward that whistleblowers receive when both they and the government adopt the positive strategy.	$R_2 \geq 0$
M	The gains obtained by the public when all three subjects choose the positive strategy.	$M \geq 0$
α	The coefficient of reward provided by the government to whistleblowers.	$0 \leq \alpha < 1$
β	The rate of propaganda of the early warning mechanism through whistleblowing	$0 \leq \beta < 1$
θ	The efficiency of the government's response to the warnings or the level of its risk perception.	$0 \leq \theta < 1$
ω	The coefficient of the whistleblowers' professional competence and literacy, or the level of their risk perception.	$0 \leq \omega < 1$
μ	The coefficient of the public's ability to discern the warnings or the level of its risk perception.	$0 \leq \mu < 1$

Assumption 3: This paper uses the concept of the evolutionary game to analyze dynamic changes in each subject's behaviors. If we consider the specific mechanisms of information, risk perception, and preventive behavior, the model becomes too complex. To simplify it, we assume that a high level of risk perception leads to more comprehensive protective measures, thereby reducing the loss of risk experienced by individuals and society. This criterion is used to set up the payoff matrix.

Assumption 4: In the early warning period of public health emergencies, the government may adopt some necessary emergency measures and incur cost C_1. If the government adopts the strategy of positive guidance, it yields an additional expenditure K_2 for the government due to the construction of the mechanism, expanding the channels for making a voice available to whistleblowers, and publicizing the policy and mobilizing society to construct an early warning mechanism through whistleblowing. We denote the rate of propaganda of the early warning mechanism through whistleblowing or the degree of the government's efforts to build the mechanism by β. The government's expenditure on mechanism construction is βK_2. The larger β is, the greater the number of channels that the government can set up for whistleblowers to make a voice and for social mobilization, and the higher the cost of building the corresponding mechanism. In addition, when the government adopts the positive guidance, it awards material rewards K_1 to whistleblowers who make a voice positively and reacts to the warnings in a timely manner after receiving the warnings disclosed by whistleblowers. The actual rewards αK_1 are related to the coefficient of reward α. The higher α is, the greater the reward that the government needs to pay to whistleblowers. The efficiency of its response to the warnings refers to the level of the government's risk perception, θ. The cost of the government's response to the warnings K_3 is related to θ, and the actual cost incurred by it is θK_3. Similarly, a higher efficiency of the response to the warnings indicates that the government has a higher level of risk perception, and it needs to bear a higher cost of response in this case. If the government adopts a negative guidance strategy, there is no need for it to incur the costs of building the mechanism and rewarding whistleblowers. However, it suffers social and economic losses L_1 in this case because it takes the minimal protective measures. At the same time, the (local) government is punished by the higher-level (superior) government for ignoring the warnings. This punishment is denoted by P.

Assumption 5: If whistleblowers choose a positive vocalization strategy (making a voice), they need to pay a cost C_2 for it. If the government adopts a positive guidance strategy, it shares part of this cost paid by the whistleblower. The cost of vocalization incurred by the whistleblowers then is $(1-\beta)C_2$. As β increases, the government becomes more active in constructing the whistleblowing mechanism, and the cost of choosing a positive vocalization strategy for the whistleblower is lower at this time. Moreover, whistleblowers receive material reward R_1 and reputational reward R_2 from the government when the government also chooses the positive strategy. The values of R_1 and R_2 are related to the coefficient of reward α and the level of the government's risk perception θ. Therefore, the total rewards received by whistleblowers are $\alpha\theta(R_1+ R_2)$. As part of the public, whistleblowers also suffer economic and security-related losses L_2 as a result of the outbreak of disease. The losses to them are related to their professional competence ω. If they have a high professional aptitude and are more likely to identify new threatening viruses, their level of risk perception is higher in the early warning period of the public health emergencies. We can assume that the whistleblowers' professional competence is equivalent to their level of risk perception in the model. The higher the whistleblower's risk perception is, the greater the value of the warnings released by them. At this point, the information provided in the warnings are more important in improving the risk perceptions of the government and the public and they are more likely to take preventive measures. The losses incurred by the whistleblowers and the government in this case are $(1-\omega)L_2$ and $(1-\omega)L_1$, respectively.

Assumption 6: If the public chooses the strategy of positive cooperation and acts according to the information released by the whistleblowers, it incurs a cost of cooperation C_3, such as purchasing of protective equipment, voluntarily reporting of abnormal situations, and the loss of the opportunity to work or go outdoor. When the public chooses a negative cooperation strategy and is unwilling to act according to the whistleblowers' warnings, the economic and security-related losses to the public are L_3. When both the whistleblowers and the public choose a positive strategy, the losses suffered by the public are $(1-\omega)(1-\mu)L_3$. We introduce μ as the level of the public's risk perception. It also signifies the public's ability to discern the warning messages. If μ is larger, the public has a higher level of risk perception and a stronger ability to identify the warnings. The higher the level of the whistleblowers' risk perception ω is, the greater is the potential for their warnings to improve the public's risk perception. According to assumption 3, the public takes comprehensive precautions at this point and correspondingly suffers lower losses. Likewise, when the public and the whistleblower both adopt a positive strategy, the losses to the government and whistleblower are reduced to $(1-\omega)(1-\mu)L_1$ and $(1-\omega)(1-\mu)L_2$,

respectively. At this point, if the government also adopts a positive guidance strategy, the gain in prevention and control achieved by the public is θM and the government's gain from it is θG. The more effective the government's response to the warnings is or the higher its level of risk perception, the greater the benefits of prevention and control for the public and the government.

Payoff Matrix and Model Construction

Combined with the problem description and the above assumptions, we construct a payoff matrix for the government, whistleblowers, and the public under different strategy choices during the early warning period of the public health emergencies. The payoff matrix is shown in Table 2 and Table 3.

The expected benefit obtained by the government when it chooses a positive guidance strategy E_{A1} is as follows:

Table 2 The Payoff Matrix of the Evolutionary Game Model Under the Public's Positive Cooperation Strategy

Game Subject and Game Strategy				**The Public**
				Positive Cooperation (z)
The Government	Positive guidance (x)	The Whistleblowers	Positive vocalization (y)	$-C_1-(1-\omega)(1-\mu)L_1-\alpha K_1-\beta K_2-\theta K_3+\theta G$, $-(1-\beta)C_2-(1-\omega)(1-\mu)L_2+\alpha\theta(R_1+R_2)$, $-C_3-(1-\omega)(1-\mu)L_3+\theta M$
			Negative vocalization ($1-y$)	$-C_1-(1-\mu)L_1-\beta K_2$, $-(1-\mu)L_2$, $-C_3-(1-\mu)L_3$
	Negative guidance ($1-x$)		Positive vocalization (y)	$-C_1-(1-\omega)(1-\mu)L_1-P$, $-C_2-(1-\omega)(1-\mu)L_2$, $-C_3-(1-\omega)(1-\mu)L_3$
			Negative vocalization ($1-y$)	$-C_1-(1-\mu)L_1-P$, $-(1-\mu)L_2$, $-C_3-(1-\mu)L_3$

Table 3 The Payoff Matrix of the Evolutionary Game Model Under the Public's Negative Cooperation Strategy

Game Subject and Game Strategy				**The Public**
				Negative Cooperation (1–z)
The Government	Positive guidance (x)	The Whistleblowers	Positive vocalization (y)	$-C_1-(1-\omega)L_1-\alpha K_1-\beta K_2-\theta K_3$, $-(1-\beta)C_2-(1-\omega)L_2+\alpha\theta(R_1+R_2)$, $-L_3$
			Negative vocalization ($1-y$)	$-C_1-L_1-\beta K_2$, $-L_2$, $-L_3$
	Negative guidance ($1-x$)		Positive vocalization (y)	$-C_1-(1-\omega)L_1-P$, $-C_2-(1-\omega)L_2$, $-L_3$
			Negative vocalization ($1-y$)	$-C_1-L_1-P$, $-L_2$, $-L_3$

$$E_{A1} = yz[-C_1 - (1-\omega)(1-\mu)L_1 - \alpha K_1 - \beta K_2 - \theta K_3 + \theta G] + y(1-z)[-C_1 - (1-\omega)L_1 - \alpha K_1 - \beta K_2 - \theta K_3] + (1-y)z[-C_1 - (1-\mu)L_1 - \beta K_2] + (1-y)(1-z)(-C_1 - L_1 - \beta K_2) \quad (1)$$

The expected benefit obtained by the government when it chooses a negative guidance strategy E_{A2} is as follows:

$$E_{A2} = yz[-C_1 - (1-\omega)(1-\mu)L_1 - P] + y(1-z)[-C_1 - (1-\omega)L_1 - P] + (1-y)z[-C_1 - (1-\mu)L_1 - P] + (1-y)(1-z)(-C_1 - L_1 - P) \quad (2)$$

The average benefit obtained by the government for selecting a strategy $\bar{E}_A$ is as follows:

$$\bar{E}_A = xE_{A1} + (1-x)E_{A2} \quad (3)$$

According to the equation of Malthusian dynamics, the equation for the replication dynamic of the government's guidance strategy F_x can be regarded as:

$$F_x = \frac{dx}{dt} = x(\bar{E}_A - E_{A1}) = x(1-x)(E_{A1} - E_{A2}) = x(1-x)[P - \beta K_2 - y(\alpha K_1 + \theta K_3) + yz\theta G] \quad (4)$$

The derivative of F_x is as follows:

$$F_x' = (1-2x)[P - \beta K_2 - y(\alpha K_1 + \theta K_3) + yz\theta G] \quad (5)$$

The expected benefit obtained by the whistleblowers when they choose a positive vocalization strategy E_{B1} is as follows:

$$E_{B1} = xz[-(1-\beta)C_2 - (1-\omega)(1-\mu)L_2 + \alpha\theta(R_1 + R_2)] + x(1-z)[-(1-\beta)C_2 - (1-\omega)L_2 + \alpha\theta(R_1 + R_2)] + (1-x)z[-C_2 - (1-\omega)(1-\mu)L_2] + (1-x)(1-z)[-C_2 - (1-\omega)L_2] \quad (6)$$

The expected benefit obtained by the whistleblowers when they choose a negative vocalization strategy E_{B2} is as follows:

$$E_{B2} = xz[-(1-\mu)L_2] + x(1-z)(-L_2) + (1-x)z[-(1-\mu)L_2] + (1-x)(1-z)(-L_2) \quad (7)$$

The average benefit obtained by the whistleblowers for choosing a strategy E_{B1} is as follows:

$$\bar{E}_B = yE_{B1} + (1-y)E_{B2} \quad (8)$$

According to the equation of Malthusian dynamics, the equation for the replication dynamic of the whistleblowers' vocalization strategy F_x can be regarded as:

$$F_y = \frac{dy}{dt} = y(\bar{E}_B - E_{B1}) = y(1-y)(E_{B1} - E_{B2}) = y(1-y)[-C_2 + \omega L_2 + x\beta C_2 + x\alpha\theta(R_1 + R_2) - z\mu\omega L_2] \quad (9)$$

The derivative of F_x is as follows:

$$F_y' = (1-2y)[-C_2 + \omega L_2 + x\beta C_2 + x\alpha\theta(R_1 + R_2) - z\mu\omega L_2] \quad (10)$$

As in the above, the expected benefit obtained by the public when it chooses a positive cooperation strategy E_{C1} is as follows:

$$E_{C1} = xy[-C_3 - (1-\omega)(1-\mu)L_3 + \theta M] + x(1-y)[-C_3 - (1-\mu)L_3] + (1-x)y[-C_3 - (1-\omega)(1-\mu)L_3] + (1-x)(1-y)[-C_3 - (1-\mu)L_3] \quad (11)$$

The expected benefit obtained by the public when it chooses a negative cooperation strategy E_{C2} is as follows:

$$E_{C2} = xy(-L_3) + x(1-y)(-L_3) + (1-x)y(-L_3) + (1-x)(1-y)(-L_3) \quad (12)$$

The average benefit obtained by the public for choosing a strategy $\bar{E}_C$ is as follows:

$$\bar{E}_C = zE_{C1} + (1-z)E_{C2} \quad (13)$$

According to the equation of Malthusian dynamics, the equation for the replication dynamic of the public's cooperation strategy F_z can be regarded as:

$$F_z = z(1-z)[-C_3 + \mu L_3 + xy\theta M + yL_3(\omega - \omega\mu)] \tag{14}$$

The derivative of F_z is as follows:

$$F_z' = (1-2z)[-C_3 + \mu L_3 + xy\theta M + yL_3(\omega - \omega\mu)] \tag{15}$$

Simulation Analysis of Evolutionary Game Model of the Early Warning of Public Health Emergencies Through Whistleblowing

We used numerical simulations to specify the dynamic evolutionary paths of the strategy choices of the government, whistleblowers, and the public. Several representative parameters were considered, and the specific mechanism of impact of these parameters on each subject's behavioral strategy was explored by changing the parameters' value. Based on the investigations of empirical scenarios in the early warning period of public health emergencies as well as consultations with the relevant experts, we set the initial values of parameters and the changed values of some specific parameters in the model. The specific parameters settings are shown in Table 4. The initial probability of each subject's selection of a positive strategy in the game system was set to 0.5.

The ethical approval is not required as the research mainly applies mathematical analysis and simulation. The research also does not involve case reports, clinical trials, animals and other data that require approval for use. But the consent has been already obtained from the relevant experts who participate in the study.

Effect of α on the Evolution of the Subjects' Strategies

The reward coefficient α was set to 0.1, 0.3, 0.5, 0.7, and 0.9. The evolutionary trajectories of the behaviors of the government, whistleblowers, and the public as obtained by the simulation are shown in Figure 2. When α was low, such as α=0.1 and α=0.3, the choice of strategy of the government converged toward positive guidance, as shown in (Figure 2b). Combined with (Figure 2c), the evolutionary trajectory of the whistleblowers' behavior showed a trend of cyclical fluctuations when the government provided little reward to them for making a voice. The evolutionary trajectory of the whistleblowers' behavior exhibited a wider range of fluctuations and a higher peak when α was 0.3. In this case, they had a higher probability of choosing the positive vocalization strategy compared with that at α=0.1 because they

Table 4 The Values of the Parameters in the Model

Parameter	The Initial Values	The Changed Values			
C_1	30	–	–	–	–
C_2	16	–	–	–	–
C_3	12	–	–	–	–
L_1	30	–	–	–	–
L_2	20	–	–	–	–
L_3	15	–	–	–	–
K_1	12	–	–	–	–
K_2	20	–	–	–	–
K_3	12	–	–	–	–
G	12	–	–	–	–
P	20	–	–	–	–
R_1	5	–	–	–	–
R_2	8	–	–	–	–
M	10	–	–	–	–
α	0.5	0.1	0.3	0.7	0.9
β	0.5	0.1	0.3	0.7	0.9
θ	0.5	0.1	0.3	0.7	0.9
μ	0.5	0.1	0.3	0.7	0.9
ω	0.5	0.1	0.3	0.7	0.9

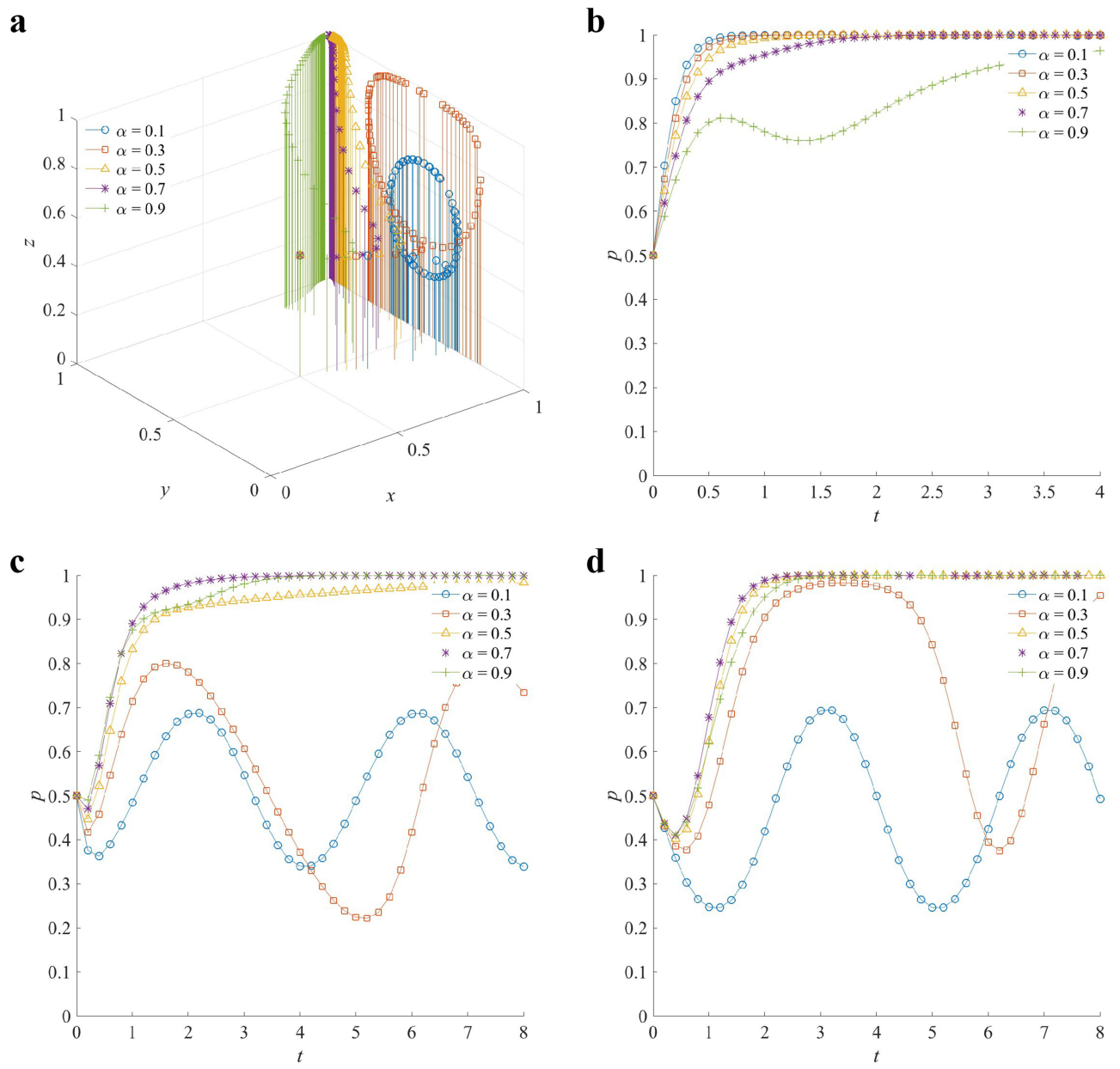

Figure 2 Results of simulations of the evolutionary game system with changes in α. (**a–d**) are the evolutionary trajectories of the game system, the government, the whistleblowers and the public, respectively.

could obtain more rewards from the government. As α continued to increase, the whistleblowers' behavioral strategy converged to that of positive vocalization while the government's behavioral trajectory moved toward positive guidance, but the speed of the government' s convergence gradually decreased. In particular, when α=0.9, the evolutionary trajectory of the government's behavior fluctuated slightly, which indicates that the cost incurred by it for offering rewards increased with the increase in the reward coefficient α. This increase in cost had some negative implications for the government's adoption of a positive guidance strategy. The speed of convergence of the whistleblowers' positive vocalization dropped when α=0.9 compared with that when α=0.7. We analyzed this phenomenon in combination with (Figure 2b). The evolutionary trajectory of the government's behavior fluctuated slightly and reduced the speed of convergence to positive guidance when α=0.9. Affected by the government's behavior, the speed of convergence of the whistleblowers' strategy to positive vocalization also decreased in parallel. (Figure 2d) shows that the public and the whistleblowers formed a hybrid strategy with periodic fluctuations when the value of the reward coefficient was low

(α=0.1 and α=0.3). However, when α was set to 0.5, 0.7, and 0.9, the evolutionary trajectory of the public's behavior was consistent with that of the whistleblowers, and the game system eventually converged to (1,1,1). These results show that the whistleblowers' choice to voicing had a significant effect on the public's adoption of the positive cooperation strategy, and that the strategy choices of both whistleblowers and the public were influenced by the government's behavior.

Effect of β on the Evolution of the Subjects' Strategies

The rate of propaganda of the early warning mechanism through whistleblowing β was set to 0.1, 0.3, 0.5, 0.7, and 0.9. The evolutionary trajectories of the behaviors of the government, whistleblowers, and the public as obtained by the simulations are shown in Figure 3. An increase in β implied that the government had increased the publicity of the mechanism, and the cost of strengthening the mechanism increased correspondingly. Consequently, the speed of convergence of the government's strategy to positive guidance decreased, as shown in (Figure 3b). When β=0.9, the

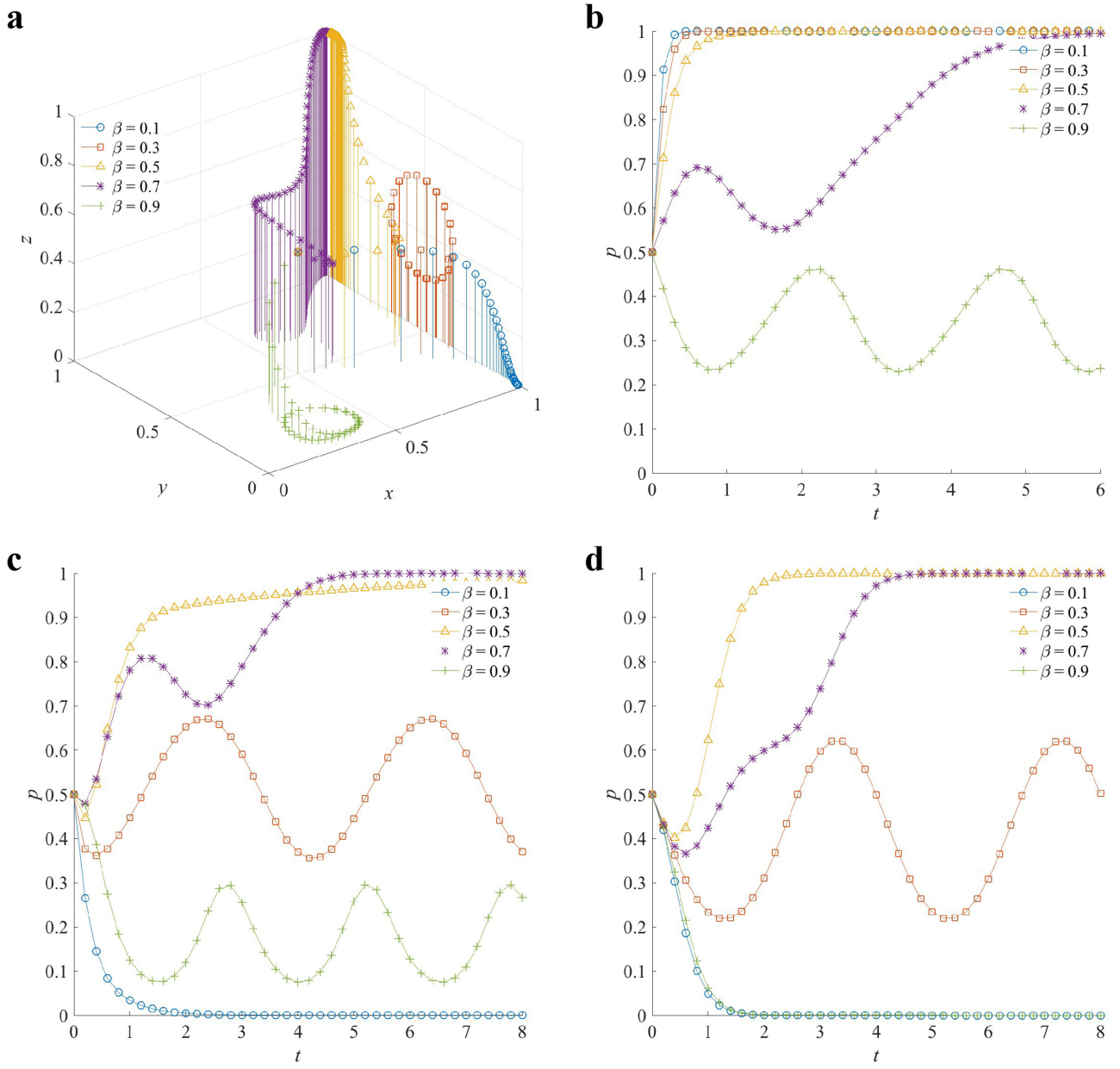

Figure 3 Results of simulations of the evolutionary game system with changes in β. (**a–d**) are the evolutionary trajectories of the game system, the government, the whistleblowers and the public, respectively.

government's behavior had a tendency to fluctuate, and there was a high probability that it would choose the negative guidance strategy, as shown in (Figure 3a). Changing the value of β had a direct influence on the whistleblowers' strategy selection. (Figure 3c) shows that when β was low (β=0.1), the whistleblowers' behavioral trajectory evolved to the negative vocalization strategy because fewer channels were available to them to make a voice and they had to bear a higher cost for doing so. As β increased to 0.3, a cyclically fluctuating strategy of "negative cooperation and positive vocalization" was assumed by the public and the whistleblowers, respectively. The whistleblowers were hesitant to adopt the positive strategy at this time. As β continued to rise to 0.5, the government attached greater importance to the construction of the whistleblowing mechanism. It bore part of the cost of vocalization and built a comprehensive platform to encourage whistleblowers to come forward. With the support of the government, the whistleblowers' willingness to voicing grew, and their behavioral trajectory shifted toward the positive vocalization strategy. As β was increased further, the whistleblowers' behavior began to oscillate under the influence of the government's strategy selection. When β=0.7, for example, the whistleblowers' behavior fluctuated for a short period but still converged to the positive strategy. By the time β reached its maximum value of 0.9, the whistleblowers' behavioral trajectory showed a reciprocating trend, and was more inclined to the negative strategy. (Figure 3d) shows the influence of β on the public's behavioral trajectory. When β was too high or too low (β=0.1 or β=0.9), the public adopted a negative strategy because the whistleblowers released less risk-related information and the public had low risk perception. Under this condition, the system converged to the strategy combination of (1,0,0) as shown in (Figure 3a). When β was 0.5 or 0.7, the evolutionary trajectory of the public's behavior was consistent with that of the whistleblowers but lagged behind, indicating that the evolution of the public's behavior was influenced by the urgency of the warnings released by whistleblowers and constrained by the government's behavior.

Effects of θ on the Evolution of the Subjects' Strategies

The efficiency of the government's response to warnings or its risk perception θ was set to 0.1, 0.3, 0.5, 0.7, and 0.9. The evolutionary trajectories of the behaviors of the government, whistleblowers, and the public as obtained by the simulations are shown in Figure 4. (Figure 4a) shows that the stable combination of strategies of the game system was (1,1,0) when θ was low (θ=0.1). At this time, the government and the whistleblowers chose the positive strategy while the public chose the negative strategy. As θ increased, the behaviors of all three subjects converged to positive strategies and the game system eventually stabilized at (1,1,1). Regardless of the value of θ, the government's behavior tended toward the positive guidance strategy and its rate of convergence was almost constant, as shown in (Figure 4b). This is because it is the government's responsibility to respond to the warnings. The government always chose the positive strategy under the supervision of the superior government and the public, even if it had to bear the extra cost. (Figure 4d) shows that the government's risk perception had a significant impact on the evolution of the public's behavior. When the government had insufficient risk perception and did not respond to the warnings in a timely manner (θ=0.1), the public's behaviors switched to the negative cooperation strategy. When θ=0.3, the behavioral trajectories of both the public and the whistleblowers exhibited unstable fluctuations, as shown in (Figures 4d and c). The government adopted a more active attitude to guide the public to take preventive actions compared with the situation when θ=0.1, and the degree of cooperation between the government and the public increased under the guidance of the government. At this point, the whistleblowers' vocalization had no significant effect on the public's strategy selection. Therefore, the probability of the whistleblowers' voicing decreased correspondingly. However, when the probability of the public choosing positive cooperation decreased, the whistleblowers began to change their behavioral strategy such that it evolved to positive vocalization. When the government's risk perception increased (θ was set to 0.5, 0.7, or 0.9), it played a dominant role in guiding the public. The government took mandatory measures to encourage the public to ensure personal protection. The rewards due to the whistleblowers for vocalization also increased. Owing to the joint effort by the government and the whistleblowers, all three subjects assumed a stable strategy combination of positive guidance, positive vocalization, and positive cooperation.

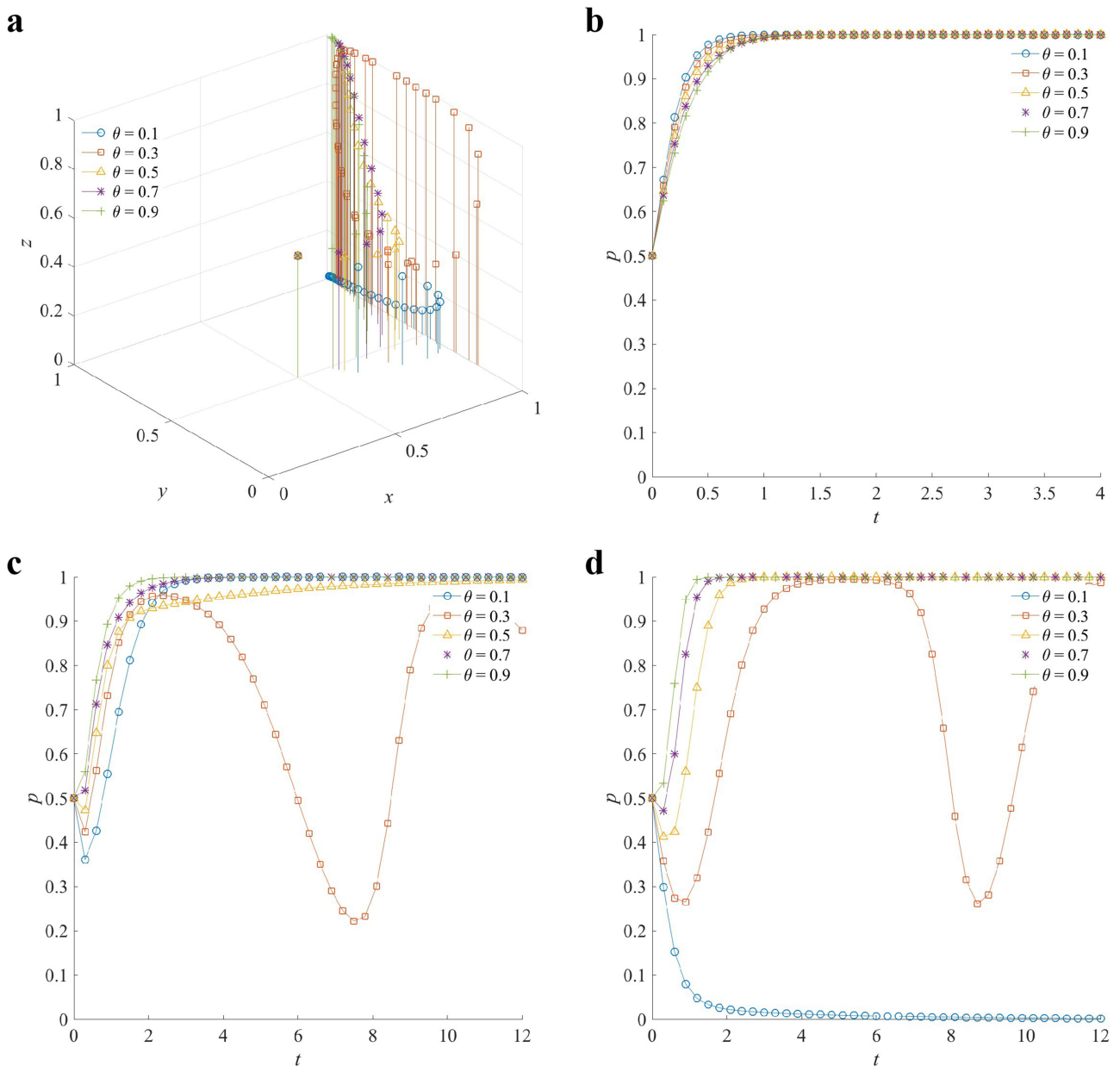

Figure 4 Results of simulations of the evolutionary game system with changes in θ. (**a–d**) are the evolutionary trajectories of the game system, the government, the whistleblowers and the public, respectively.

Effects of ω on the Evolution of the Subjects' Strategies

The coefficient of the whistleblowers' professional competence or their risk perception ω was set to 0.1, 0.3, 0.5, 0.7, and 0.9. The evolutionary trajectories of the behaviors of the government, whistleblowers, and the public as obtained by the simulations are shown in Figure 5. When ω=0.1, the strategy combination of the system converged to (1,0,0), and only the government chose a positive strategy as shown in (Figure 5a). To prevent the risk from spreading, ensuring necessary prevention and control of the emergency at hand, and guiding the public to take protective measures are part of the government's responsibility. At this point, whistleblowers, with a low risk perception, and the public, lacking early warnings, both preferred negative strategies. When ω=0.3, the public and the whistleblowers formed a mixed strategy of "negative cooperation and positive vocalization" with periodic fluctuations in reciprocity. In this case, the warnings released by whistleblowers could not induce the public to choose a positive strategy because the authenticity of the

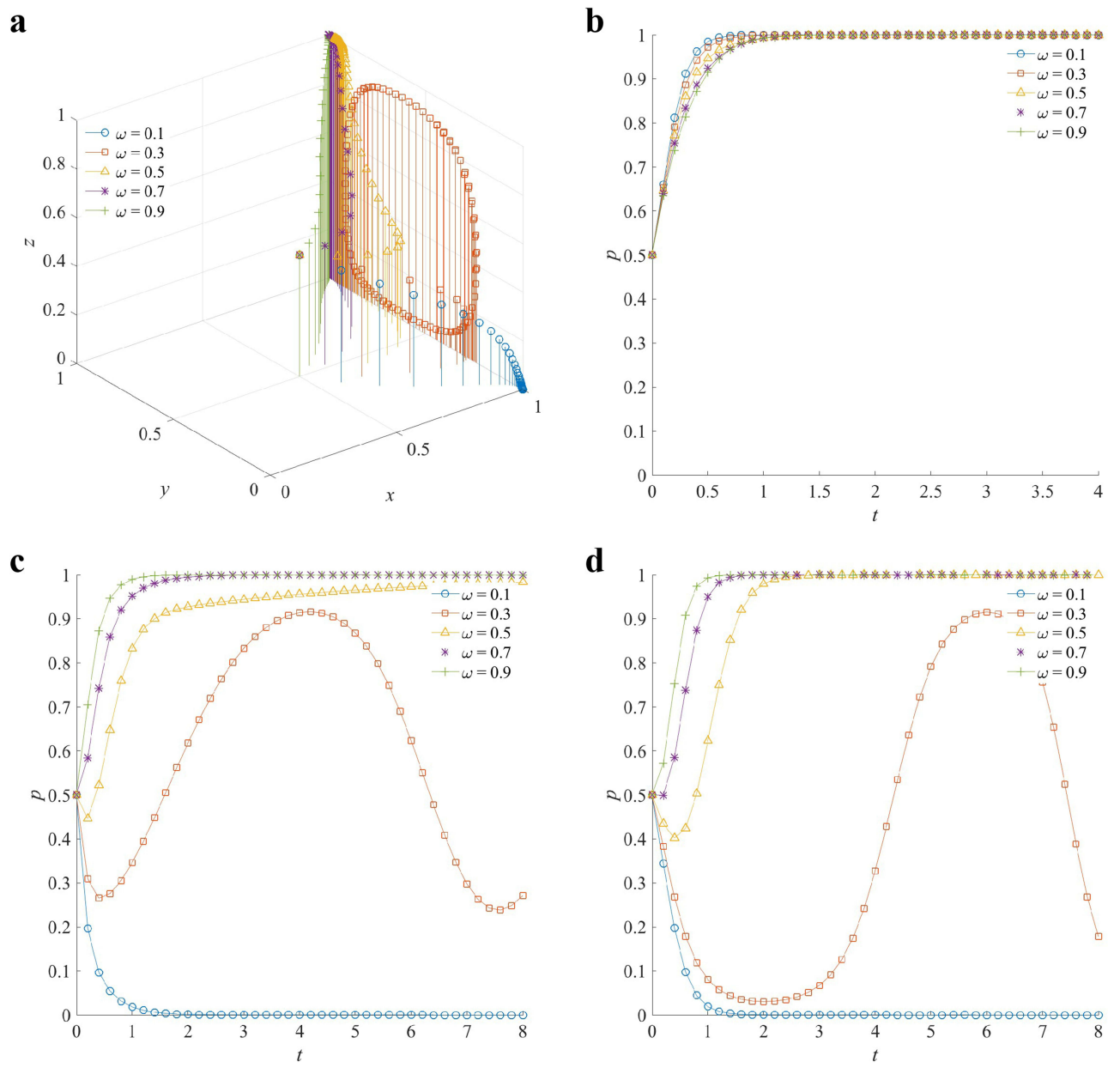

Figure 5 Results of simulations of the evolutionary game system with changes in ω. (**a–d**) are the evolutionary trajectories of the game system, the government, the whistleblowers and the public, respectively.

information had not been confirmed, and the public was hesitant about which strategy to choose in light of the costs and benefits of each. With the increase in ω, the whistleblowers' professional ability increased and the warnings released by them became more valuable. The whistleblowers' behavioral strategy changed from negative vocalization to cyclical fluctuation and then to positive vocalization as shown in (Figure 5c). However, the speed with which the government converged to the positive guidance gradually decreased as the whistleblowers' behavioral strategy evolved toward positive vocalization, as is clear from the comparison between (Figures 5b and c). One possible explanation for this phenomenon is that when the whistleblowers' competence increased, their disclosures of warnings were more accurate and had a greater effect in improving the level of the public's risk perception. Therefore, the public was more willing to adopt measures in light of the warnings released by the whistleblowers and modify its strategy to that of active cooperation with the government. Whistleblowers with a higher level of risk perception could help the government

share some of the responsibility for guiding the public, because of which the rate at which the government's strategy converged to positive guidance decreased.

Effects of μ on the Evolution of the Subjects' Strategies

The coefficient of the public's ability to discern the warnings or its risk perception μ was set to 0.1, 0.3, 0.5, 0.7, and 0.9 respectively. The evolutionary trajectories of the behaviors of the government, whistleblowers, and the public as obtained by the simulations are shown in Figure 6. In the initial stage of the emergency, the signs of risk had not fully manifested, because of which members of the public did not have a clear idea of it owing to a low level of risk perception (μ=0.1). Whistleblowers, as the part of the public, also did not have a comprehensive grasp of the risk-related information and released less useful information. Thus, the public's behavioral trajectory evolved to the negative strategy while the whistleblowers and the government assumed a mixed strategy of cyclical oscillations, as shown in (Figure 6a). The signs

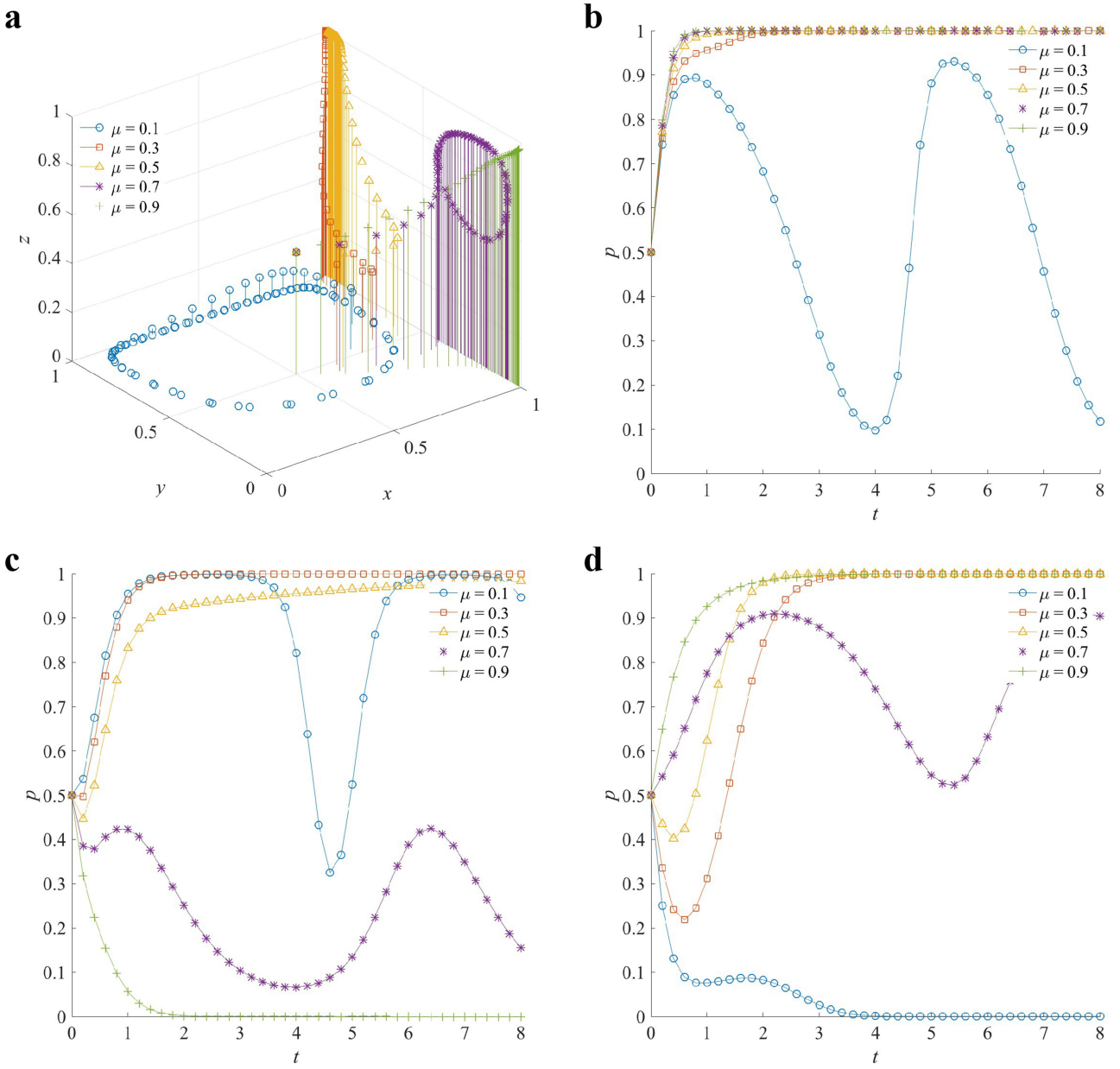

Figure 6 Results of simulations of the evolutionary game system with changes in μ. (**a–d**) are the evolutionary trajectories of the game system, the government, the whistleblowers and the public, respectively.

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of risk became more prominent as μ increased to 0.3, and the whistleblowers tended to choose the active vocalization strategy. In this period, the risk-related information released by whistleblowers attracted the attention of the government and the public, and their behavioral strategies evolved toward positive guidance and cooperation, respectively. In the case of μ=0.5, the public's behavioral strategy converged to the positive strategy at a higher rate. Because of the high degree of cooperation between the public and the government, the rate at which the whistleblowers' behavioral strategy converged to active vocalization gradually decreased, as shown in (Figure 6c). When μ increased to 0.7, the public's behavioral trajectory was not stable, as shown in (Figure 6d), even though it had a high risk perception. This is because when the public had a higher risk perception, it was more likely to choose the positive cooperation strategy, however, whistleblowers tended to choose a negative vocalization strategy owing to the public's high risk perception as well as the good cooperation between the public and the government. There was a corresponding decrease in the amount of the risk-related information released by whistleblowers, which in turn reduced the probability of the public choosing the positive strategy. Therefore, the behavioral strategies of the public and whistleblowers oscillated, and could not stabilize to either the positive or the negative strategy. Similarly, when μ continued to increase to 0.9, the public's behavioral strategy converged to positive cooperation at a higher speed owing to its high risk perception and the government's positive guidance. At this point, the whistleblowers' behavioral trajectory evolved toward the negative vocalization strategy, and the game system finally formed a stable strategy combination of (1,0,1) consisting of positive guidance, negative vocalization, and positive cooperation.

Discussion

The early warning of the risk posed by public health emergencies is a process of coordination and interaction among multiple agents, not only within in countries but also between the developed, developing countries.[54] Typical features of the early warning period include the fuzzy cognition of risk and uncertain risk perception. The collaboration between subjects is key to accurately assessing the risk and improving the effectiveness of warnings about it. Based on the typical characteristics of uncertain risk perception, the evolutionary game model of the early warning of public health emergencies through whistleblowing composed of the government, whistleblowers, and the public showed the specific mechanism of behavioral evolution and strategy selections of different subjects. The reason we select α, β, θ, μ, and ω as variable parameters is changing the values of these parameters can make the results of the research are more innovative and inspiring. The numerical simulations above clarified the internal operating states of the evolutionary game system, and can help improve the efficiency of the early warning of the risk posed by public health emergencies. The results of the numerical simulations can also provide a reference for optimizing the construction of the relevant mechanism.

In general, when the government, whistleblowers, and the public adopted positive strategies, the loss of risk to society as a whole was minimal. At this point, the disease did not spread widely and the risk posed by it stabilized to within a controllable range. The subjects were not always active in the initial stage, and the evolution of their behaviors was constrained by the realistic premise of bounded rationality and cost. The behavioral strategies of the government, whistleblowers, and the public dynamically changed through mutual restraint and influence, but eventually stabilized in light of the goal of optimality of the system and the maximization of their own benefits. The above analysis allowed us to fully explore the core elements of the early warning mechanism of public health emergencies through whistleblowing.

Most studies on public health emergencies have focused on remedial measures and interventionist policies after the outbreak of risk, and few have used mathematical methods to determine how to effectively prevent and control risk in the early warning period of public health emergencies. In contrast to previous studies in the area, ours fully considered the functions of whistleblowers in medicine and healthcare, and focused on building an early warning mechanism of public health emergencies through whistleblowing. To bring our research more closely in line with the empirical situation, we incorporated the levels of risk perception of different subjects into the process of building models based on risk perception theory. We assumed that the risk perception influenced the behavioral choices of the subjects and thus had different effects on them in terms of risk-induced loss. A higher level of risk perception can encourage subjects to take the necessary preventive actions, and can reduce economic and health-related losses for them.[55] We used numerical simulations to examine changes in the entire game system when different subjects had different levels of risk perception, and revealed the mechanism of influence of risk perception on the evolution of the system.

Research from the perspective of the whistleblowers not only enriches the research content of the warning of risk, but also expands the field's research reach in risk governance. In the process of the transformation from risk management to risk governance, establishing and refining the early warning mechanism of public health emergencies through whistleblowing is an effective means of motivating public participation and developing a model for the joint governance of risk. Viewed from another perspective, it is also an important transformation of the governance of public affairs, and helps optimize reforms in the medical and healthcare systems. The parameters set by the model and the results of simulations provide suggestions and schemes for the government to improve the construction of the mechanism. Moreover, the operational states of the game system and the evolutionary paths of all three subjects' behavioral strategies provide theoretical validation for the operation of the mechanism. The results of this study make an objective description of the situation in China. However, the findings also have theoretical and practical significance for other countries in terms of establishing an effective early warning mechanism of public health emergencies through whistleblowing to contain diseases. In addition to the level of risk perception, information acquisition, and the cost of behavior, the subject's emotional state, educational background, and other factors are known to affect their behavioral strategies. These factors were not considered in the proposed model to emphasize the importance of risk perception. Future studies in the area should consider these factors and determine whether they influence the results of prevalent models. While we have explored the early warning mechanism of public health emergencies through whistleblowing and drawn conclusions that were consistent with empirical scenarios, the specific practices of it and the interactions among subjects under different scenarios need to be further explored in future work.

Conclusions

In this paper, the authors constructed an evolutionary game model of the early warning mechanism of public health emergencies through whistleblowing by considering the uncertainty of the subjects' risk perception, and discussed the necessity and the urgency of the establishment of the early warning mechanism in medicine and healthcare. We analyze the factors influencing the subjects' strategy selection and the mutual influence among the subjects. Numerical simulations were used to provide a clear description of the evolutionary trajectories of the subjects' behaviors and their stable strategies. The following conclusions were obtained:

(1) Increasing the whistleblowers' reward, optimizing the reward program for them, and improving the rate of propaganda of the early warning mechanism through whistleblowing could increase the probability of whistleblowers choosing to make a voice and the public choosing to cooperate with the government. In addition to improving the efficiency of risk governance, these measures motivate the public to participate in risk monitoring and early warning in case of public health emergencies. The government, however, is sensitive to the cost of building the relevant mechanism. Increasing rewards for whistleblowers and publicizing the early warning mechanism through whistleblowing are indeed conducive to forming a model of risk governance with diversified and joint governance. However, when the cost of building the mechanism exceeds a certain threshold, the government reduces its efforts such that this makes it difficult for whistleblowers and the public to choose positive vocalization and positive cooperation, respectively.

(2) Although responding to the warnings is part of the responsibility of the government, its level of risk perception, namely, the efficiency of its response, has a significant positive effect on motivating the public and whistleblowers to take positive actions. A government with a higher risk perception responds more quickly to the warnings and adopts the requisite measures to contain the spread of risk. The government's measures send a signal of the risk to the public to enhance its awareness. The public is in turn more likely to cooperate with the government under its guidance. The reward for whistleblowers is directly proportional to the efficiency of the government's response to the information or its risk perception. As a result, the more efficient is the government's response to information, the more willing are whistleblowers to speak out.

(3) Whistleblowers who are professionally competent or have a high risk perception can provide more accurate warnings. The warnings can improve the public's risk perception and motivate them to take protective measures to reduce the overall risk. However, only when the whistleblowers' have a certain level of professional competence does the risk-related information released by them have value for the government and the public, and only then does the effect of the early warning mechanism through whistleblowing gradually become prominent. The strategy combination of "positive vocalization and positive cooperation" for the whistleblowers and the public, respectively, not only improves

the overall risk perception in society, but helps with the early detection and prevention of the emergency. Therefore, competent whistleblowers can form a linkage with the government, and can urge the public to cooperate with the government's work by adopting the necessary preventive measures of their own accord. This can also help improve the efficiency of risk prevention and control.

(4) The public is sensitive to warnings, and the quantity and quality of the risk-related information released by whistleblowers can encourage it to cooperate with the government's risk prevention work. It is at this stage that whistleblowers act as a bridge between the government and the public, and play an important role in sounding the alarm regarding an outbreak. Therefore, constructing the early warning mechanism through whistleblowing and encouraging whistleblowers to speak out are effective means of motivating the public to take protective measures, reducing the losses due to risk, and preventing the further spread of the disease. However, improving the public's ability to discern warning messages or its risk perception has an inhibitory effect on the whistleblowers' vocalization. If the public's risk perception is high, it takes the initiative in adopting the corresponding measures to cooperate with the government's risk prevention work. In this case, the whistleblowers' vocalization has no prominent influence on strategy selection by the government and the public, and whistleblowers are thus more inclined to choose not to speak out.

Implications

In light of the findings of this study, we suggest the following measures for the construction of the early warning mechanism of public health emergencies through whistleblowing:

(1) When public health emergencies arise, different subjects have different levels of risk perception. The government should establish a early warning mechanism of public health emergencies through whistleblowing for the early detection and prevention of the risk, motivate clinicians and other frontline medical staff to come forward and disclose the risk-related information, and take timely containment measures to prevent the widespread dissemination of the disease. To encourage whistleblowers to speak out, the government should increase the amount of reward due to them and make sure that they promptly receive it. Moreover, the government should publicize the early warning mechanism in daily life to gain the trust of whistleblowers. Specifically, the government should establish more channels through which whistleblowers' can make a voice and provide convenient platforms for them. The government should also consider whether the cost of building the mechanism exceeds the scope of its fiscal budget. A certain part of the funds can be drawn from the daily financial budget to avoid exceeding the set financial limits.

(2) The government and the whistleblowers should improve their risk perception. Synergistic cooperation between them has a significant effect on social mobilization. To form an interactive relationship with the whistleblowers, the government should promptly listen and respond to their warnings. Risk prevention by the government is also an important safeguard for improving social capacity to prevent and control the risk. On the one hand, officials in the government should enhance their awareness and perceptions of risks. It is only when they realize the urgency and necessity of preventing or defusing risk that they can carry out the subsequent work for risk prevention. Having obtained information from whistleblowers, the government should develop a plan of action in response and organize experts to conduct a detailed investigation. On the other hand, whistleblowers need to have a keen perception of the risk and an excellent ability to identify it. Reporting any unusual case in this regard can help inform the public and the government of the risk posed by an outbreak.

(3) The government should strengthen the construction of the early warning mechanism of public health emergencies through whistleblowing beforehand, rather than taking action only once the risk posed by an emergency has become prominent. Each public health emergency has particular features, where this makes it challenging for the public, which lacks the requisite professional knowledge, to have a clear understanding of the risk during the early warning period. Consider SARS and the COVID-19 pandemic as examples, although both are major infectious diseases, they did not draw public attention at the outset. The government can remedy this in the future by building an early warning mechanism of public health emergencies through whistleblowing, strengthening the society mobilization and incentivizing the expression of relevant opinions by whistleblowers. The government should also encourage whistleblowers to improve their professional competence and ability to identify risks. In this way, the government can quickly activate the early warning mechanism of public health emergencies through whistleblowing, and can give full play to the role of

whistleblowers as a mediator between the government and the public. This can lead to the formation of a pluralistic model of risk governance that is guided by the government, and features the active involvement of the public.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors have no conflicts of interest in this study.

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