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Research Article

Directing the Diffusion of Public Opinions in Incidents with Not-in-My-Back-Yard Projects: An Evolutionary Perspective

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How should the public administrative department direct the diffusion of public opinions in a not-in-my-backyard (NIMBY) crisis? This paper first analyzes the macroevolutionary characteristics of the public opinion associated with a NIMBY crisis. We then examine the perceptive interactions among individuals towards NIMBY projects from a microscopic perspective and develop an evolutionary game model (i.e., replicator dynamics) to describe the interactions among individuals. We also use information entropy and dynamic equations to construct an interaction entropy model and a dynamic equation to capture administrative-department-led public opinion. Through examining the existence and stability of the evolutionary equilibrium of these models, we analyze the evolution of NIMBY public opinion.

1. Introduction

Not-in-my-backyard (NIMBY) refers to the individual reaction of "do not build in my backyard" when facing the construction of some facilities with negative impacts on human health, environmental quality, and asset values. Examples include garbage dumps, funeral parlors, and nuclear power plants [1]. According to statistics from the State Department of Environmental Protection, mass incidents associated with NIMBY projects in recent years have remained at an average annual growth rate of 29% in China. The primary reason for these NIMBY incidents characterized by "interest demand" is the formation and development of NIMBY public opinion. Here, public opinion is the synthesis of the public emotions, attitudes, and views that the public masses have formed on a specific project [2]. If there is no public consensus on a NIMBY project, it would be impossible to perform a concerted action among individuals, and no public incidents would happen. In particular, with the increasing use of the Internet as a channel to share public opinion, mass NIMBY incidents have become more frequent in recent years, such as the typical "PX (paraxylene) incidents" that occurred recently in Ningbo Zhejiang, Kunming Yunnan, and Maoming Guangdong, which even triggered a secondary public opinion crisis and may severely hinder economic and social development. However, with the increasing occurrence of NIMBY incidents, the local public administrative department usually pays more attention to how to effectively control an emergency of a public incident than only focusing on individuals' perceptions of NIMBY projects [3]. This results in individuals' rights to fully know the projects and their perception bias towards the potential risks being overlooked, causing the public's opinion on the NIMBY projects to be more intense. Therefore, how to examine the evolutionary law of public opinion related to NIMBY projects has become an important issue for the local public administrative department to effectively control the public's opinion and avoid potential conflicts. This paper also examines the following important problems: What are the impacts of public perception and the guidance of the public administrative department on the evolution of the public opinion regarding a NIMBY project? What are the dynamic equations of the evolution of public's opinion in a NIMBY project? Is the evolution of public opinion toward a

NIMBY project stable across scenarios? How should a public administrative department effectively manage public opinion after a NIMBY incident happens?

Previous literature quantitatively investigated the evolutionary mechanism of public opinion from both macro and micro perspectives. In terms of macromodeling, the susceptible-infected-recovered (SIR) model has been extensively used to capture the evolutionary mechanism [4]. In this line of literature, Qiu et al. [5] conducted simulations of rumor propagation by incorporating time-dependent propagation behavior into the SIR model. Jiang and Yan [6] extended the SIR model by using the node degree to capture the dynamic evolution of a group spreading rumors. Taking rumor propagation in a multilingual environment into account, Wang et al. [7] developed an SIR model with a cross-propagation mechanism. Regarding micromodeling, Sznajd [8] used a discrete model to describe how the neighboring nodes in a public-opinion network choose their neighbors. In contrast, Hegselmann and Krause [9] depicted the interactions between individuals and their neighbors through a continuous model. In addition, some scholars used evolutionary game models to examine the evolution of public opinion based on bounded rationality (i.e., the learning and imitation interactions among individuals). In this regard, based on an evolutionary game analysis of opinion dynamics, Etesami and Başar [10] transformed the asynchronous evolution of the model in Hegselmann and Krause [9] into a potential game with the most adaptive change sequence. Yang [11] built a public opinion evolution model based on individual imitation behavior and applied it to study scale-free networks. In addition, to better simulate the microinteractions among individuals, multiagent modeling approaches have also been applied to investigate the evolution of public opinion, which integrates social contact, the environment, psychology, as well as individuals' opinions. For example, combining text mining with network topology, Ma and Liu [12] used the public opinion supernetwork model to identify public opinion leaders, and Zhu et al. [13] examined the interaction between information diffusion and the evolution of public opinion in online social networks. In addition, some scholars also put forward the concept of social physics to explain different social phenomena, such as critical behavior, large-scale migration, epidemiology, environmental challenges, and climate change [14]. Coincidentally, Helbing et al. [15] proposed that a suitable system design and management can help to stop undesirable cascade effects and enable favorable kinds of self-organization in the system.

Although these models attach great importance to the influence of individual microbehavior on the evolution of public opinion, they fail to capture the behavioral interaction among individuals when facing opposite views, which makes it difficult to highlight the influence of public perception and the guidance of public administrative departments on the evolution of public opinion. Compared with the general online public opinion, the NIMBY public opinion shows a stronger interaction with reality [16]. Accordingly, this requires the public administrative department to effectively guide public opinion on a NIMBY project by interacting with public opinion when responding to the NIMBY conflict in order to minimize or suppress the suddenness of group incidents. From the perspective of the evolution of public opinion, this paper explores the evolutionary law of public opinion in a NIMBY conflict and then analyzes how the public administrative department adjusts its management strategy to properly control the NIMBY conflict.

This paper differs from the literature in the following two ways: (1) The macromodeling and micromodeling frameworks are integrated to analyze the evolution of complex neighbors and public opinion in a NIMBY conflict. Here, at the macrolevel, this paper revises the Gompertz model in the literature; while at the micro level, we develop a public opinion evolutionary model to capture the NIMBY conflict by accounting for the individual-interaction behaviors. (2) According to the negative aspect of the NIMBY opinion, this paper uses the information entropy theory and the opinion dynamics method to construct a cross-entropy model and dynamic equation, which the public administrative department can use to effectively manage the public opinion in a NIMBY incident.

2. Evolutionary Model of NIMBY Public Opinion

From the macro perspective, the curve-movement characteristics of the Gompertz model can reflect the dynamic trend of the accumulated information on the public opinion of a NIMBY project over time [17]. However, the Gompertz model cannot fully characterize the influence of the public perception of the project risks and their interactive behaviors at the micro level. In fact, public opinion of NIMBY projects mainly sprouts from the public's perception bias towards the project's risk, and it spreads and diffuses rapidly with the exchange of mutual information. For example, when people perceive the danger of PX, they tend to exaggerate the potential losses caused by PX when communicating with others through social media. In this setting, much of the negative information about PX may turn into a rumor and spread immediately. Moreover, people will eventually reach a consensus on their perception of the project risk and share this consistent opinion through a communication network or other ways. In this way, to capture the influence of perceptive interactions among individuals towards the project risk on the evolution of NIMBY public opinion, a revised dynamic of the traditional Gompertz model is given as follows [18]:

$$\frac{\mathrm{d}y}{\mathrm{d}t} = rx(t)y(t)\ln\left(\frac{N}{-y(t)}\right), \quad 0 \le x(t) \le 1, \quad y(t) < 0, \quad r > 0, \quad N > 0. \tag{1}$$

In this equation, $y(t)$ refers to the cumulative amount of negative information about NIMBY public opinion at time t, $y(t) < 0$ represents the negative influence of NIMBY public opinion, and $x(t)$ is the probability or frequency of information exchange among individuals about the risks of neighboring projects at time t. The term $rx(t)$ indicates the diffusion speed of the public opinion regarding a NIMBY project and is proportional to the interaction frequency among individuals, where r is the proportionality coefficient and N signifies the final saturation value of the public opinion.

For equation (1), it is natural to raise the following two questions:

(1) What is the dynamic equation of $x(t)$, which can be used to examine the influence of $x(t)$ on $y(t)$ and analyze the evolution of the corresponding dynamic system?

(2) To explore the influence of guidance of the public administrative department on the evolution of public opinion in a NIMBY project, how do we describe the interaction between the administrative-department-led opinion $z(t)$ and the public opinion $y(t)$, and how can we derive a dynamic equation satisfied by $z(t)$?

Therefore, based on the evolutionary game theory, a replication dynamic equation is constructed, which describes the interaction of the individual behaviors towards the risk associated with NIMBY projects and the administrative-department-led public opinion. Meanwhile, information entropy and dynamic methods are used to construct the interaction entropy model and the dynamic equation of administrative-department-led public opinion, and derive a dynamic model to capture the evolution of public opinion related to NIMBY projects.

2.1. The Replicator Dynamic Equation for Individual Interactions. The public's opinion on NIMBY projects primarily results from the public's perception of the potential risks associated with the projects. Assume that the actual loss to an individual resulting from the project risk is $\widetilde{S}$, the probability of $\widetilde{S} = s$ is q, and the probability of $\widetilde{S} = 0$ is $1 - q$. Then, the project risk is qs. However, due to the public perceptive bias towards the project risk, the prospect theory can be applied to build the individual's utility function as follows [19]:

$$u_i(\widetilde{S}) = -r_i qs,\ r_i \geq 1, \quad i = 1, 2, \cdots, n. \tag{2}$$

In this equation, r_i measures the individual i's perception of the project risk. $r_i > 1$ implies that the individual overestimates the project risk and amplifies her own losses, whereas $r_i = 1$ indicates that the individual's perception of the project risk is completely rational. Accordingly, $r_i q$ can be viewed as the individual's subjective probability. Equation (2) shows that the individual's perception of the project risk has a negative effect on her utility. Moreover, the greater the project risk or the higher the degree of an individual's perception is, the greater this negative effect on the utility will be.

When individuals perceive the risk of NIMBY projects and communicate through a social network, a community network is thus formed. Individuals interact with their neighbors in the network in two ways: (1) accepting the opinions of others and sharing them with neighbors, and (2) rejecting others' opinions and keeping their own perceptions. Thus, interactions between individuals can be expressed as $S = \{s_1, s_2\} = \{\text{accept}, \text{reject}\}$. When all individuals choose the strategy s_2, they will not communicate with each other but instead only share the value of network information V. In this case, each individual and her neighbors both have the utility V. In contrast, when all individuals choose the strategy s_1, they not only obtain the value of network information V but also enjoy the value $\rho_{ij}V$ through sharing their information. Here, ρ_{ij} measures the degree of interaction between an individual i and her neighbor j. Obviously, the higher the degree of the interaction, the greater the benefit obtained from the social interaction. The degree of interaction between two individuals is related to the project's risk and each individual's perception of the potential risk. In other words, the greater the project risk or the more sensitive the individual is to the project risk, the higher the individual's tendency to interact with others [9, 20]. Thus, according to equation (2), ρ_{ij} can be expressed as

$$\rho_{ij} = \frac{qs\sqrt{u_i u_j}}{\left|u_i - u_j\right|} = \frac{qs\sqrt{r_i r_j}}{\left|r_i - r_j\right|} = \frac{qs}{\sigma_{ij}},\ i \neq j, i, j = 1, 2, \ldots, n. \tag{3}$$

In the equation, $\sigma_{ij} = |r_i - r_j| / \sqrt{r_i r_j}$ refers to the relative difference of the perception between individuals i and j. Equation (3) shows that the greater the project risk or the smaller the perceptive bias towards the risk between two individuals, the stronger the individual's desire to interact, and the greater the degree of interaction between individuals.

When individuals share their perceptions of the risk of NIMBY projects, they often incur a sharing cost C. Since the interaction between individuals is a two-way network, the individual i and her neighbor j have the same payment $\rho_{ij}V + V - C$ when they choose the same strategy s_1.

Therefore, based on the game-learning perspective of perceptive interactions between two individuals, we can derive the strategy combinations of the interactions and the corresponding payment matrix A. (See Table 1).

Since individuals usually have limited perceptions of the potential risk associated with NIMBY projects, they thus prefer to frequently modify and improve their perceptions through learning, trial, and imitation when interacting with their neighbors. Therefore, according to the replicator dynamics in the evolutionary game theory, the individual interaction frequency $x(t)$ satisfies the following equation [21]:

Table 1: Payment matrix between two individuals.

Individual i	Neighbor j	
	Accept (s_1)	Reject s_2
Accept (s_1)	$\rho_{ij}V+V-C$, $\rho_{ij}V+V-C$	$\rho_{ij}V+V-C$, V
Reject (s_2)	V, $\rho_{ij}V+V-C$	V, V

$$\begin{aligned}\frac{\mathrm{d}x}{\mathrm{d}t} &= x(t)\left[(1,0)\cdot A\cdot(x(t),1-x(t))^T-(x(t),1-x(t))\cdot A\cdot(x(t),1-x(t))^T\right]\\ &=\left(\rho_{ij}V-C\right)x(t)[1-x(t)],\ i\neq j,\quad i,j=1,2,\ldots,n.\end{aligned}\tag{4}$$

In this equation, "T" stands for the matrix transpose, and $x(t)$ indicates the probability of an individual choosing strategy s_1, namely, the individual interaction frequency.

2.2. Modeling the Guidance of Public Administrative Department. As individuals recognize the risk of NIMBY projects and share their perceptions through social networks, the project risk will be magnified by public irrationality and prejudice and can spread rapidly through the network. If the public administrative department cannot properly react to the public's opinion in a timely way, the rapid spread of public opinion would result in a dramatic negative effect on society [22]. Recall the interaction between the administrative-department-led positive public opinion $z(t)$ and the public's negative public opinion $y(t)$. Building on the information entropy [20], the joint entropy and interaction entropy of $z(t)$ and $y(t)$ can be defined as follows:

$$H(z,y)=-\omega\log_2\omega-(1-\omega)\log_2(1-\omega),\quad \omega=\frac{z(t)}{z(t)-y(t)},\tag{5}$$

$$J(z,y)=\begin{cases}y(t)[1-H(z,y)], & \omega\in(0,0.5),\\ z(t)[1-H(z,y)], & \omega\in[0.5,1).\end{cases}\tag{6}$$

The system, including equations (5) and (6), is the cross-entropy model of administrative-department-led public opinion. Equation (5) represents the information entropy composed of positive administrative-department-led public opinion and negative public opinion, where ω is the proportion of administrative-department-led public opinion. Equation (6) indicates the interaction rule between positive and negative public opinions, which is dependent on the value of ω. When $\omega\in(0,0.5)$, the negative public opinion dominates and the interaction entropy is negative. As ω increases, the negative influence decreases, i.e., $\partial H/\partial\omega>0$, and the administrative-department-led public opinion is passive. However, when $\omega\in[0.5,1)$, the positive administrative-department-led public opinion dominates and the interaction entropy is positive. As the value of ω increases, the positive effect becomes larger, i.e., $\partial H/\partial\omega<0$, and the administrative-department-led public opinion is active.

The key method for a public administrative department to guide the public's opinion regarding a NIMBY project is to respond timely. To capture the different response paths, the following dynamic equation is used to capture the administrative department's public opinion:

$$\frac{\mathrm{d}z}{\mathrm{d}t}=\varepsilon z(t)+(1-\delta)y(t-\phi),\quad 0\leq\varepsilon\leq 1,\ 0\leq\delta\leq 1,\ \phi\geq 0.\tag{7}$$

In this equation, ϕ refers to the time delay in the response of the administrative department to public opinion. ε represents the update of the administrative-department-led public opinion, whereas $1-\varepsilon$ can be viewed as the effectiveness of the administrative-department-led public opinion. δ refers to the degree to which the public administrative department intends to avoid the public's opinion, while $1-\delta$ measures the administrative department's concern or respect for the public's opinion on a NIMBY project.

2.3. The Evolution Dynamics of Public Opinion. No matter how administrative-department-led public opinion interacts with public opinion, the resulting cross-entropy will have a certain impact on the evolution of public opinion. Let $\eta\geq 0$ denote this effect. Based on equations (1), (4), (7), and (6), the evolutionary model of public opinion can be given as follows:

$$\begin{cases}\dfrac{\mathrm{d}x}{\mathrm{d}t}=\left(\rho_{ij}V-C\right)x(t)[1-x(t)],\\[2ex] \dfrac{\mathrm{d}y}{\mathrm{d}t}=rx(t)y(t)\ln\left[\dfrac{N}{-y(t)}\right]+\eta J(z(t),y(t-\phi)),\\[2ex] \dfrac{\mathrm{d}z}{\mathrm{d}t}=\varepsilon z(t)+(1-\delta)y(t-\phi).\end{cases}\tag{8}$$

According to the dynamic system (8), the role of the administrative department can be divided into two types: passive guidance and active guidance, as shown in Table 2.

3. Stability Analysis

3.1. Passive Guidance. In this case, based on the conditions in Table 2, we assume that $z(t)=z_0$ and $0<z_0<N$. Therefore, the system (8) can be rewritten as

Table 2: Two types of evolutionary systems of NIMBY public opinion.

	Passive guidance	Active guidance
Conditions	$\eta > 0,\ \phi > 0,\ 0 < \omega < 0.5$	$\eta > 0,\ \phi = 0,\ 0.5 \le \omega < 1$

$$\begin{cases} \dfrac{dx}{dt} = \left(\rho_{ij}V - C\right)x(t)[1 - x(t)], \\ \dfrac{dy}{dt} = rx(t)y(t)\ln\left[\dfrac{N}{-y(t)}\right] + \eta y(t-\phi)[1 - H(z_0, y)(t-\phi)]. \end{cases} \quad (9)$$

The evolutionary properties of the system (9) are summarized in the following Propositions 1, 2, and 3.

Proposition 1. *If $\sigma_{ij} \ne qsV/C$ ($\forall$, $i \ne j$, $i, j = 1, 2, \ldots, n$), the evolutionary system (9) has the equilibrium points $(0, -z_0)$ and $(1, \overline{N})$, where $\overline{N} \in (N, +\infty)$ satisfies the following condition with $\lim_{r \longrightarrow 0^+}(d\overline{N}/dz_0) > 0$ or $\lim_{n \longrightarrow +\infty}(d\overline{N}/dz_0) > 0$:*

$$F(\overline{N}) = r\,\ln\left[\frac{N}{\overline{N}}\right] + \eta[1 - H(z_0, -\overline{N})] = 0. \quad (10)$$

Proof. If $(\overline{x}, \overline{y})$ is the equilibrium point of system (9), $(\overline{x}, \overline{y})$ must satisfy the following equations:

$$\begin{cases} \left(\rho_{ij}V - C\right)\overline{x}(1 - \overline{x}) = 0, \\ \overline{y}\left[r\overline{x}\ln\left(\dfrac{N}{-\overline{y}}\right) + \eta(1 - H(z_0, \overline{y}))\right] = 0. \end{cases} \quad (11)$$

If $\sigma_{ij} \ne qsV/C$, i.e., $\rho_{ij}V \ne C$, equation (11) has the two solutions of $(\overline{x}, \overline{y}) = (0, -z_0)$ and $(\overline{x}, \overline{y}) = (1, -\overline{N})$, where $\overline{N}$ is the solution of $F(\overline{N}) = 0$.

When $z_0 < N$, $F(N) > 0$ and $\lim_{\overline{N} \longrightarrow +\infty} F(\overline{N}) = -\infty$. Therefore, $\overline{N} \in (N, +\infty)$ such that $F(\overline{N}) = 0$.

For both sides of the equation $F(\overline{N}) = 0$, taking the derivative with respect to z_0 yields the following equation:

$$\frac{d\overline{N}}{dz_0} = \frac{\overline{N}}{z_0 + (r/\eta)\cdot\left(\left(z_0 + \overline{N}\right)^2/\overline{N}\log_2(z_0/\overline{N})\right)}. \quad (12)$$

It can be seen that if $r \longrightarrow 0^+$ or $\eta \longrightarrow +\infty$, then, $d\overline{N}/dz_0 = \overline{N}/z_0 > 0$, and therefore $\lim_{r \longrightarrow 0^+}(d\overline{N}/dz_0) > 0$ or $\lim_{n \longrightarrow +\infty}(d\overline{N}/dz_0) > 0$. □

Proposition 2. *Given $\phi \ge 0$. When $\sigma_{ij} > qsV/C$, the evolutionary system (9) is locally stable at the equilibrium point $(0, -z_0)$. In contrast, when $\sigma_{ij} < qsV/C$, the stability of the evolutionary system (9) at equilibrium point $(1, -\overline{N})$ is derived as follows:*

(1) If $r = u$, the equilibrium point $(1, -\overline{N})$ is locally stable; and

(2) If $r > u$, there is a time-delayed increasing sequence $\phi_k \in (0, +\infty)$ $(k = 1, 2, 3 \cdots)$ such that $(1, -\overline{N})$ is locally stable when $\phi = 0, \phi_1, \phi_2, \cdots$ and unstable when $\phi \in (0, \phi_1) \cup (\phi_1, \phi_2) \cup \cdots$, where $f_k(\phi_k) = 0$. The functional sequence $f_k(\phi)$ and parameters u and v are, respectively, defined as

$$\begin{aligned} f_k(\phi) &= \phi e^{(v-u+r)\phi} - \frac{(4k-1)\pi}{2v}, \quad k = 1, 2, 3 \ldots \\ u &= -\frac{\eta z_0\overline{N}}{\left(z_0 + \overline{N}\right)^2}\log_2\left(\frac{z_0}{\overline{N}}\right) > 0, \\ v &= \eta\left[1 - H(z_0, -\overline{N}) - \frac{z_0\overline{N}}{\left(z_0 + \overline{N}\right)^2}\log_2\left(\frac{z_0}{\overline{N}}\right)\right] > 0, \\ v &= \eta[1 - H(z_0, -\overline{N})] + u > 0. \end{aligned} \quad (13)$$

Proof. First, the characteristic equation of system (9) at the equilibrium point $(0, -z_0)$ is

$$\lambda\left(\lambda - \rho_{ij}V + C\right) = 0. \quad (14)$$

Hence, when $\sigma_{ij} > qsV/C$, the eigenvalue is given as $\lambda = \rho_{ij}V - C < 0$ or $\lambda = 0$. Thus, according to the stability condition, the equilibrium point $(0, -z_0)$ is locally stable. □

Proof. Second, the characteristic equation of system (9) at equilibrium point $(1, -\overline{N})$ is

$$\left(\lambda - C + \rho_{ij}V\right)\left[v\lambda\int_{-\phi}^{0} e^{\lambda s}ds + \lambda - u + r\right] = 0. \quad (15)$$

Equation (15) has at least one real root, $C - \rho_{ij}V$. Therefore, according to the stability condition, if $\sigma_{ij} > qsV/C$, then, the equilibrium point $(1, -\overline{N})$ should be unstable; meanwhile, if $\sigma_{ij} < qsV/C$, the stability of the equilibrium point $(1, -\overline{N})$ depends on the following equation:

$$p(\lambda) = v\lambda\int_{-\phi}^{0} e^{\lambda s}ds + \lambda - u + r = 0. \quad (16)$$

For equation (16), if $r < u$, there must be $p(0) = r - u < 0$ or $\lim_{\lambda \longrightarrow +\infty} p(\lambda) = +\infty$. Moreover, since $p'(\lambda) = v\phi e^{-\lambda\phi} + 1 > 0$, the equation $p(\lambda) = 0$ should have a unique positive root. Therefore, the point $(1, -\overline{N})$ should be unstable. If $r = u$, the solution of equation $p(\lambda) = 0$ is $\lambda = 0$. It can be shown that system (9) is locally stable at the point $(1, -\overline{N})$.

Therefore, when $\sigma_{ij} < qsV/C$ and $r > u$, system (9) is locally stable at the point $(1, -\overline{N})$ if and only if all the roots of the equation $p(\lambda) = 0$ have a negative real part, that is, $\forall\lambda$, and $\mathrm{Re}(\lambda) < 0$ [23].

For the equation $p(\lambda) = 0$, if $\phi = 0$, then, the root is $\lambda = u - r < 0$. Hence, the point $(1, -\overline{N})$ should be locally stable, whereas if $\phi > 0$, then, the stability of the point $(1, -\overline{N})$ depends on the symbol of $\mathrm{Re}(d\lambda/d\phi)|_{\phi=0, \lambda=u-r}$.

Take the derivatives of both sides of the equation (16) with respect to ϕ as follows:

$$v\left\{\frac{d\lambda}{d\phi}\int_{-\phi}^{0} e^{\lambda s}ds + \lambda\left[e^{-\lambda\phi} + \frac{d\lambda}{d\phi}\int_{-\phi}^{0} se^{\lambda s}ds\right]\right\} + \frac{d\lambda}{d\phi} = 0. \tag{17}$$

It thus follows that

$$\frac{d\lambda}{d\phi} = -\frac{v\lambda e^{-\lambda\phi}}{1 + \int_{-\phi}^{0}(v + \lambda s)e^{\lambda s}ds}. \tag{18}$$

Moreover,

$$\operatorname{Re}\left(\frac{d\lambda}{d\phi}\right)|_{\phi=0,\lambda=u-r} = -v(u - r) > 0. \tag{19}$$

Equation (19) shows that there exists a sufficiently small $\phi_1 > 0$ such that if $\phi \in (0, \phi_1)$, then all roots of the equation $p(\lambda) = 0$ satisfy $\operatorname{Re}(\lambda) > 0$. Meanwhile, if $\phi = \phi_1$, then, $\operatorname{Re}(\lambda) < 0$, that is, there exist values $a < 0$ and $b > 0$ such that the value $\lambda = a \pm bi$ satisfies the equation $p(\lambda) = 0$. The necessary and sufficient conditions for the equation $p(a + bi) = 0$ or $p(a - bi) = 0$ are, respectively, given as follows:

$$ve^{-a\phi}\sin(b\phi) = -b, \tag{20}$$

$$ve^{-a\phi}\cos(b\phi) = a + v - u + r. \tag{21}$$

Assume that $a = -(v - u + r)$. It thus follows that

$$ve^{(v-u+r)\phi} = b, \tag{22}$$

$$b\phi = \frac{(4k - 1)\pi}{2}, \quad k = 1, 2, 3, \cdots. \tag{23}$$

According to equations (22) and (23), eliminating parameter ϕ leads to the following equation:

$$f_k(\phi) = \phi e^{(v-u+r)\phi} - \frac{(4k - 1)\pi}{2v} = 0, \quad k = 1, 2, 3\cdots. \tag{24}$$

Since $f_k(0) < 0$, $\lim_{\phi\longrightarrow+\infty} f_k(\phi) = +\infty$ and $f_k'(\phi) > 0$, the equation $f_k(\phi) = 0$ has a unique solution $\phi_k \in (0, +\infty)$. Taking the derivative of both sides of the equation $f_k(\phi) = 0$ with respect to k results in

$$\frac{d\phi_k}{dk} = \frac{2\pi}{[1 + (v - u + r)\phi]ve^{(v-u+r)\phi}} > 0. \tag{25}$$

According to equation (25), it can be shown that $\phi_k \in (0, +\infty)$ is an increasing sequence, namely, $0 < \phi_1 < \phi_2 < \cdots < +\infty$.

When ϕ_k is uniquely determined by the equation $f_k(\phi) = 0$, $b_k = ve^{(v-u+r)\phi_k}$ can be obtained from the equation (20), and the root of equation $p(\lambda) = 0$ is $\lambda = -(v - u + r) + b_k i$. Similarly, it can be shown that

$$\operatorname{Re}\left(\frac{d\lambda}{d\phi}\right)|_{\phi=\phi_k,\lambda=-(v-u+r)+b_k i} = \operatorname{Re}\left(\frac{b_k^2 + ib_k(v - u + r)}{1 + v\phi_k}\right) = \frac{b_k^2}{1 + v\phi_k} > 0, \quad k = 1, 2, 3, \ldots. \tag{26}$$

Thus, we set $\phi_0 = 0$. Then, when $\sigma_{ij} < qsV/C$ and $r > u$, the equilibrium point $(1, -\overline{N})$ of system (9) is locally stable at $\phi = \phi_j$ $(j = 0, 1, 2, 3\ldots)$ and unstable at $\phi \in \cup_{j=0}^{\infty}(\phi_j, \phi_{j+1})$. This proposition is thus proved. □

Proposition 3. *If the equilibrium point $(1, -\overline{N})$ of the evolutionary system (9) is locally stable at $\phi = \phi_k$, there must be $d\overline{N}/d\phi_k < 0$, where ϕ_k is the unique solution of the equation $f_k(\phi) = 0$ $(k = 1, 2, 3\ldots)$.*

Proof. First, for equation $f_k(\phi) = 0$ in (25), the derivative with respect to $\overline{N}$ is

$$\frac{d\phi_k}{d\overline{N}} = \frac{\phi_k((du/d\overline{N}) - (dv/d\overline{N})) - (1/v)\cdot(dv/d\overline{N})}{(1/\phi_k) + v - u + r}. \tag{27}$$

Second, according to the definitions of u and v in equation (13), it follows that

$$\frac{dv}{d\overline{N}} = \frac{\eta z_0}{(z_0 + \overline{N})^2\cdot\ \ln 2}\left[1 - \frac{2z_0}{z_0 + \overline{N}}\cdot\ \ln\left(\frac{z_0}{\overline{N}}\right)\right] > 0, \tag{28}$$

$$\frac{du}{d\overline{N}} - \frac{dv}{d\overline{N}} = \frac{\eta z_0}{(z_0 + \overline{N})^2\cdot\ \ln 2}\ln\left(\frac{z_0}{\overline{N}}\right) < 0. \tag{29}$$

Then, substitute equations (28) and (29) into (27). When $u > 0$, $v > 0$, $v - u > 0$, and $\phi_k > 0$, it can be easily shown that $d\phi_k/d\overline{N} < 0$, and thereby $d\overline{N}/d\phi_k < 0$.

Propositions 1, 2, and 3 show that when the administrative-department-led public opinion is passive, the public opinion may become stronger or weaker. If there is a large discrepancy in the public perception of the risk associated with NIMBY projects (i.e., $\sigma_{ij} > qsV/C$), then due to the appropriate and timely guidance to develop a positive public opinion, individuals would gradually choose not to communicate with others in the network by constantly modifying their own perceptions. In this case, the NIMBY public opinion will rapidly evolve to a stable state $-z_0$. In contrast, if the discrepancy in the public perception of the risk is sufficiently small (i.e., $\sigma_{ij} < qsV/C$), the interactions among individuals would be frequent. This will reinforce the interaction and learning of imitation among individuals when the administrative-department-led public opinion is passive and the NIMBY public opinion evolves to a highly risky state $-\overline{N}$. Moreover, under the cases in which the public opinion itself spreads less rapidly (namely, $r \longrightarrow 0^+$) or the public administrative department enforcement is strong (namely, $\eta \longrightarrow +\infty$), the negative side of NIMBY public opinion increases with the passive response of the public administrative department. In particular, the timelier the response of the public administrative department (i.e., $\phi_k \longrightarrow 0^+$), the greater the negative impact of public opinion would be. □

3.2. Active Guidance. When the public administrative department exerts an active response to guide NIMBY public opinion, the system (9) can be expressed as follows:

$$\begin{cases} \dfrac{dx}{dt} = \left(\rho_{ij}V - C\right)x(t)[1 - x(t)], \\ \dfrac{dy}{dt} = rx(t)y(t)\ln\left[\dfrac{N}{-y(t)}\right] + \eta z(t)[1 - H(z, y)], \\ \dfrac{dz}{dt} = \varepsilon z(t) + (1 - \delta)y(t). \end{cases} \tag{30}$$

The following Propositions 4, 5, and 6 show the evolutionary properties of system (31).

Proposition 4. *If $\sigma_{ij} \neq qsV/C$ $(\forall,\ i \neq j,\ i, j = 1, 2, \cdots, n)$, then, when $\varepsilon = 1 - \delta$, the system (31) do have the equilibrium points $(1, -N, N)$ and $(0, -z^0, z^0)$, where $z^0 \in (0, +\infty)$. However, when $0 < \varepsilon < 1 - \delta$, the system (31) do have the equilibrium point $(1, -\underline{N}, (1 - \delta)\underline{N}/\varepsilon)$, where $\underline{N} \in (0, N)$ satisfies*

$$G(\underline{N}) = r\ \ln\left(\frac{N}{\underline{N}}\right) - \frac{\eta(1 - \delta)}{\varepsilon}\left[1 - H\left(\frac{1 - \delta}{\varepsilon}\underline{N}, -\underline{N}\right)\right] = 0. \tag{31}$$

Moreover, $d\underline{N}/d\varepsilon > 0$ and $d\underline{N}/d\delta > 0$.

Proof. Set $dx/dt = 0$, $dy/dt = 0$, and $dz/dt = 0$ in equation (37). Then, the equilibrium point $(\overline{x}, \overline{y}, \overline{z})$ of system (31) satisfies the following:

$$\begin{cases} \left(\rho_{ij}V - C\right)\overline{x}(1 - \overline{x}) = 0, \\ \overline{y}\left[r\overline{x}\ln\left(\dfrac{N}{-\overline{y}}\right) - \dfrac{\eta(1 - \delta)}{\varepsilon}\left(1 - H\left(\dfrac{\delta - 1}{\varepsilon}\overline{y}, \overline{y}\right)\right)\right] = 0, \\ \overline{z} = \dfrac{\delta - 1}{\varepsilon}\overline{y}. \end{cases} \tag{32}$$

For the equation (32), if $\sigma_{ij} \neq qsV/C$, namely, $\rho_{ij}V \neq C$, then its solution is as follows:

(1) If $\varepsilon = 1 - \delta$, then, the solution $(\overline{x}, \overline{y}, \overline{z})$ is $(1, -N, N)$ and $(0, -z^0, z^0)$.

(2) When $0 < \varepsilon < 1 - \delta$, the solution $(\overline{x}, \overline{y}, \overline{z})$ is $(1, -\underline{N}, (1 - \delta)\underline{N}/\varepsilon)$, where $\underline{N}$ satisfies the equation $G(\underline{N}) = 0$.

Since $G(N) < 0$ and $\lim_{\underline{N} \longrightarrow 0^+} G(\underline{N}) = +\infty$, there exists $\underline{N} \in (0, N)$ such that $G(\underline{N}) = 0$.

Taking the derivative of both sides of equation with respect to ε and δ leads to the following:

$$\begin{aligned} \frac{d\underline{N}}{d\varepsilon} &= \frac{\eta(1 - \delta)\underline{N}}{\varepsilon^2 r}\left[1 - H\left(\frac{1 - \delta}{\varepsilon}\underline{N}, -\underline{N}\right) + \frac{\varepsilon(1 - \delta)}{(1 - \delta + \varepsilon)^2}\log_2\left(\frac{1 - \delta}{\varepsilon}\right)\right] > 0, \\ \frac{d\underline{N}}{d\delta} &= \frac{\eta\underline{N}}{\varepsilon r}\left[1 - H\left(\frac{1 - \delta}{\varepsilon}\underline{N}, -\underline{N}\right) + \frac{\varepsilon(1 - \delta)}{(1 - \delta + \varepsilon)^2}\log_2\left(\frac{1 - \delta}{\varepsilon}\right)\right] > 0. \end{aligned} \tag{33}$$

This proposition is thus proved. □

Proposition 5. *If $\varepsilon = 1 - \delta = 0$, then the equilibrium point $(1, -N, N)$ is locally stable when $\sigma_{ij} < qsV/C$, whereas the equilibrium point $(0, -z^0, z^0)$ is locally stable when $\sigma_{ij} > qsV/C$.*

Proof. The characteristic equations of system (30) at the equilibrium points $(1, -N, N)$ and $(0, -z^0, z^0)$ are given as

$$(\lambda - \varepsilon)(\lambda + r)\left[\lambda - \left(C - \rho_{ij}V\right)\right] = 0, \tag{34}$$

$$\lambda(\lambda - \varepsilon)\left[\lambda - \left(\rho_{ij}V - C\right)\right] = 0. \tag{35}$$

Equations (34) and (35) show that when $\varepsilon = 0$, if $\sigma_{ij} < qsV/C$, then, the equilibrium point $(1, -N, N)$ is locally stable, whereas the equilibrium point $(0, -z^0, z^0)$ is unstable; meanwhile, if $\sigma_{ij} > qsV/C$, then, the equilibrium point $(0, -z^0, z^0)$ is locally stable, whereas the equilibrium point $(1, -N, N)$ is unstable. □

Proposition 6. *When $0 < \varepsilon < 1 - \delta$, the equilibrium point $(1, -\underline{N}, (1 - \delta)\underline{N}/\varepsilon)$ is unstable when $\sigma_{ij} > qsV/C$, but it is stable at the saddle point when $\sigma_{ij} < qsV/C$. Thus, $(1, -\underline{N}, (1 - \delta)\underline{N}/\varepsilon)$ is locally stable if and only if $x(t)$, $y(t)$, and $z(t)$ satisfy*

$$z(t) = \frac{\omega(1 - \delta)[x(t) - 1]}{\left(C - \rho_{ij}V - B_1\right)\left(C - \rho_{ij}V - \varepsilon\right) - (1 - \delta)B_2} + \frac{2(1 - \delta)\left[y(t) + \underline{N}\right]}{-\varepsilon + B_1 - \sqrt{(\varepsilon + B_1)^2 + 4\varepsilon r}} + \frac{(1 - \delta)\underline{N}}{\varepsilon}, \tag{36}$$

where

$$B_1 = -r + r\ln\left(\frac{N}{\underline{N}}\right) + \eta\left(\frac{1-\delta}{1-\delta+\varepsilon}\right)^2 \log_2\left(\frac{1-\delta}{\varepsilon}\right),$$
$$B_2 = \eta\left[1 - H\left(\frac{1-\delta}{\varepsilon}\underline{N}, -\underline{N}\right) + \frac{\varepsilon(1-\delta)}{(1-\delta+\varepsilon)^2}\log_2\left(\frac{1-\delta}{\varepsilon}\right)\right], \quad (37)$$
$$\omega = \frac{\left[\varepsilon + B_1 - \sqrt{(\varepsilon+B_1)^2 + 4\varepsilon r} - 2\left(C-\rho_{ij}V\right)\right] r\underline{N}\ln(N/\underline{N})}{\varepsilon - B_1 + \sqrt{(\varepsilon+B_1)^2+4\varepsilon r}}.$$

Proof. The Jacobian matrix of system (30) at $(1, -\underline{N}, (1-\delta)\underline{N}/\varepsilon)$ is

$$B = \begin{bmatrix} C-\rho_{ij}V & 0 & 0 \\ -r\underline{N}\ln\left(\frac{N}{\underline{N}}\right) & B_1 & B_2 \\ 0 & 1-\delta & \varepsilon \end{bmatrix}. \quad (38)$$

The characteristic equation of the matrix B is given as

$$\det(\lambda I - B) = \left[\lambda - \left(C-\rho_{ij}V\right)\right]\left[\lambda^2 - (\varepsilon+B_1)\lambda + \varepsilon B_1 - (1-\delta)B_2\right] = 0. \quad (39)$$

Substituting B_1 and B_2 into equation (39) leads to the following:

$$\left[\lambda - \left(C-\rho_{ij}V\right)\right]\left[\lambda^2 - (\varepsilon+B_1)\lambda - \varepsilon r\right] = 0. \quad (40)$$

The eigenvalues can be obtained as follows:

$$\lambda_1 = C-\rho_{ij}V, \lambda_2 = \frac{\varepsilon + B_1 + \sqrt{(\varepsilon+B_1)^2+4\varepsilon r}}{2},$$
$$\lambda_3 = \frac{\varepsilon + B_1 - \sqrt{(\varepsilon+B_1)^2+4\varepsilon r}}{2}. \quad (41)$$

Accordingly, the eigenvectors of the matrix B are given as

$$\mathrm{k}_1 = \begin{bmatrix} p \\ 1 \\ \Delta_1 \end{bmatrix}, \quad \mathrm{k}_2 = \begin{bmatrix} 0 \\ 1 \\ \Delta_2 \end{bmatrix}, \quad k_3 = \begin{bmatrix} 0 \\ 1 \\ \Delta_3 \end{bmatrix}. \quad (42)$$

where p and Δ_i $(i = 1,2,3)$ are

$$p = \frac{-\lambda_1 + B_1 + \left((1-\delta)B_2/\lambda_1 - \varepsilon\right)}{r\underline{N}\ln(N/\underline{N})},$$
$$\Delta_i = \frac{1-\delta}{\lambda_i - \varepsilon}, \quad (i = 1,2,3). \quad (43)$$

Thus, from the eigenvalues and eigenvectors of the matrix, the approximate solutions of the system (31) can be obtained as

$$x(t) = c_1 p\exp(\lambda_1 t) + 1,$$
$$y(t) = c_1\exp(\lambda_1 t) + c_2\exp(\lambda_2 t) + c_3\exp(\lambda_3 t) - \underline{N},$$
$$z(t) = c_1\Delta_1\exp(\lambda_1 t) + c_2\Delta_2\exp(\lambda_2 t) + c_3\Delta_3\exp(\lambda_3 t) + \frac{(1-\delta)\underline{N}}{\varepsilon}, \quad (44)$$

where c_1, c_2, and c_3 are constants.

There are two following cases:

(1) Case 1: If $\sigma_{ij} > qsV/C$, then $\lambda_1 = C - \rho_{ij}V > 0$, which implies that the evolutionary path of $x(t)$ is divergent and the equilibrium point $(1, -\underline{N}, (1-\delta)\underline{N}/\varepsilon)$ of the system (31) is unstable. In contrast, if $\sigma_{ij} < qsV/C$, then, the evolutionary path of $x(t)$ is convergent (i.e., $x(t) \longrightarrow 1$), which suggests that the system (31) is locally stable if and only if $y(t)$ and $z(t)$ are convergent.

(2) Case 2. If $\sigma_{ij} < qsV/C$, then $\lambda_1 < 0$, $\lambda_3 < 0$, and $\lambda_2 > 0$. Accordingly, $y(t)$ and $z(t)$ are convergent if and only if $c_2 = 0$. That is, $y(t)$ and $z(t)$ satisfy the following equations:

$$y(t) = \frac{1}{p}[x(t) - 1] + c_3\exp(\lambda_3 t) - \underline{N}, \quad (45)$$

$$z(t) = \frac{\Delta_1}{p}[x(t) - 1] + c_3\Delta_3\exp(\lambda_3 t) + \frac{(1-\delta)\underline{N}}{\varepsilon}. \quad (46)$$

Equations (45) and (46) are equivalent to the following condition:

$$z(t) = \frac{\Delta_1 - \Delta_3}{p}[x(t) - 1] + \Delta_3[y(t) + \underline{N}] + \frac{(1-\delta)\underline{N}}{\varepsilon}. \quad (47)$$

Further substituting p, Δ_i (where $i = 1, 2, 3$), λ_1, and λ_2 into the abovementioned equation leads to equation (36).

Propositions 4, 5, and 6 show that even if administrative-department-led public opinion is active, the evolution of NIMBY public opinion cannot be definitely mitigated. When the public perception of the risk is highly scattered (i.e., $\sigma_{ij} > qsV/C$), individuals tend to choose not to communicate with their neighbors in a social network, and the public administrative department can effectively control NIMBY public opinion. In such a setting, the evolution of NIMBY public opinion can converge to an intermediate steady state (i.e., stable point $-z^0$) when the public administrative department chooses appropriate guidance on positive public opinion. In sharp contrast, when the risk of the NIMBY projects is high and the public perception about the risk is less scattered (i.e., $\sigma_{ij} < qsV/C$), if the administrative department does not respect public opinion at all, it will intensify the communication among individuals on a social network such that the public opinion will quickly converge to a saturation value, i.e., the stable point $-N$. However, if the public administrative department pays more attention to the NIMBY public opinion and responds timely, the NIMBY public opinion will evolve to a highly steady state $-\underline{N}$ and will be further alleviated when the public administrative department exerts more influence on public opinion. □

3.3. Comparison of the Results. Summarizing the discussions above shows that although the response strategy to the public's opinion has a certain impact on the evolution of NIMBY public opinion, no matter what guidance the public administrative department provides, the evolution of NIMBY public opinion is highly related to the public's perception of the project risks. Therefore, from the perspective of public perception, the evolutionary equilibrium and stability of NIMBY public opinion under different situations can be summarized in Table 3.

The results in Table 3 show that when the risk of NIMBY projects is high, the public perception of the project's risk is more consistent, and individuals are more inclined to interact frequently, which leads to rapid spread of the NIMBY public opinion. This gives some insightful suggestions for the public administrative department decision-makers:

(1) When the public administrative department is passive when guiding public opinion, it can increase the supervision and punishment of rumor spreaders, increasing the individual's interaction cost, which reduces individuals' incentives to interact and tends to stabilize the evolution of public opinion. . Otherwise, public opinion will not be relieved; instead, it may evolve into a riskier state.

(2) When the guidance toward positive public opinion is active, it should give a certain degree of respect and concern to the public opinion and also follow a certain path to guide the evolution of public opinion toward stability. Otherwise, if the public administrative department cannot respect public opinion, a large amount of positive public opinion would lead to a more severe public opinion.

4. Numerical Simulation

4.1. Simulation Description. The antinuclear incident in Lianyungang originated from two articles that stated that a program of nuclear fuel reprocessing plants with a total investment of more than 100 billion yuan may be located in Lianyungang. At the beginning of July 2016, the news was communicated and discussed among circles of friends composed of Lianyungang citizens. On August 5, citizens began to protest, and thousands of citizens gathered in the streets to oppose the "nuclear waste" the following night. The two articles were read by more than 100,000 people in the subsequent three days and quickly spread on social media, causing a surge in NIMBY public opinion. In this study, this incident was selected as the basis for simulating the model, and the values of the relevant parameters are as follows:

(1) According to the relationship between the cumulative amount of public opinion data and time, the parameters in the simulation are obtained by the Gompertz curve fitting method: $N = 105686$ and $r = 0.3$.

(2) According to the Environmental Impact Assessment (EIA) for this case, the actual average loss caused by the risk of the project to the public is about s = 3000 with an objective probability of $q = 0.01$. As a result, the objective risk of the project is $qs = 30$. Moreover, since the EIA announcement was publicized online, it thus has a certain information value, which is assumed to be $V = 1$.

(3) Since the public is sensitive to the risk of the project, based on equations (2) and (3), the average discrepancy in the individual perception of the project risk can be calculated as $\overline{\sigma} = 0.1$. Without loss of generality, assume that $\sigma_{ij} = \overline{\sigma} = 0.1$.

4.2. Simulation Results. To examine the influence of the passive guidance on the evolution of NIMBY public opinion, the values of parameter C can be set as 50 and 10, and the value of ϕ is set as $\phi = 0.05, 3, 5$. The results of the simulation are shown in Figures 1 and 2.

Figures 1 and 2 show that when the guidance is sufficiently strong, individuals will be less willing to interact. In this case, if the public administrative department can provide positive guidance in a timely manner, it can correct the individual perceptions of project risks to lead to a high steady state of public opinion. In contrast, if the response of the public administrative department is lagging, the ensuing doubt will inevitably aggravate the individuals' perception

Table 3: Comparison of the evolutionary equilibrium stability of NIMBY public opinion under different scenarios.

Public perception	Public guidance	Evolutionary equilibrium point	Stability
Highly scattered ($\sigma_{ij} > qsV/C$)	Passive	$-z_0$, $z_0 \in (0, N)$	Locally stable
		$-\overline{N}$, $\overline{N} \in (N, +\infty)$	Unstable
	Active	$-z^0$, $z^0 \in (0, +\infty)$	Locally stable
		$-N$, $N \in (0, +\infty)$	Unstable
		$-\underline{N}$, $\underline{N} \in (0, N)$	Unstable
Less scattered ($\sigma_{ij} < qsV/C$)	Passive	$-z_0$, $z_0 \in (0, N)$	Unstable
		$-\overline{N}$, $\overline{N} \in (N, +\infty)$	Locally stable
	Active	$-z^0$, $z^0 \in (0, +\infty)$	Unstable
		$-N$, $N \in (0, +\infty)$	Locally stable
		$-\underline{N}$, $\underline{N} \in (0, N)$	Stable at saddle point

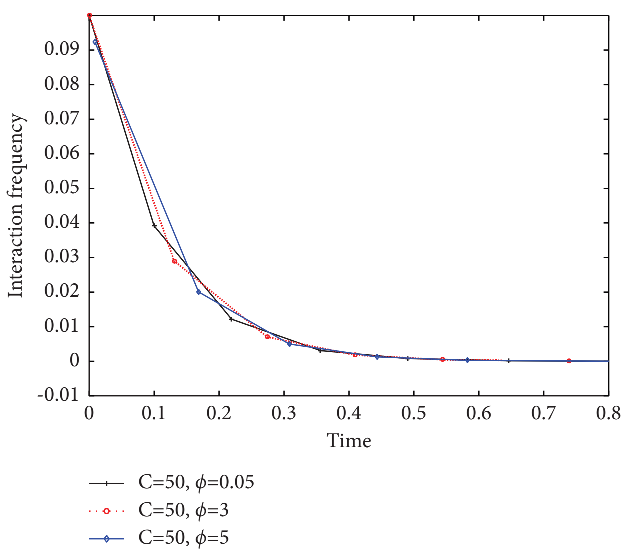

Figure 1: Influence of passive response on the evolution of interaction frequency with strong guidance.

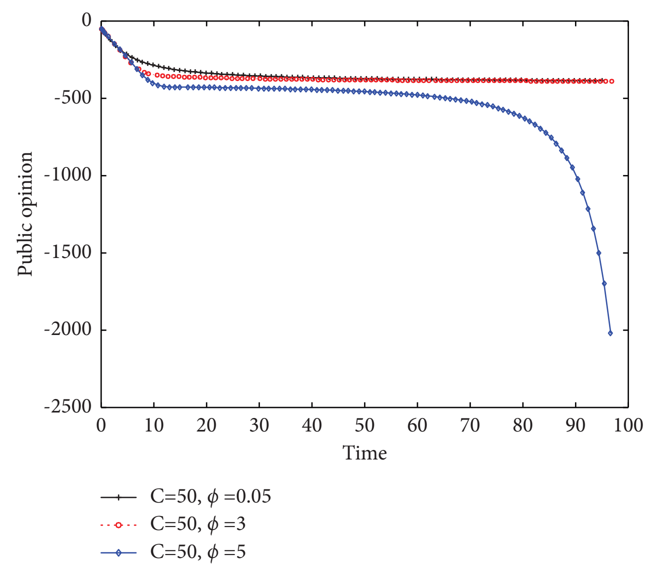

Figure 2: Influence of passive response on the evolution of NIMBY public opinion with strong guidance.

bias, which eventually causes public opinion to rebound. Moreover, Figures 3 and 4 show that when the public administrative department does not supervise or the supervision is low, individuals are inclined to communicate more frequently. If the guidance of the public administrative department for public opinion is passive, it will increase the individuals' incentives to communicate, which results in the public's opinion being far beyond the saturation state. In such a setting, public opinion would quickly evolve to a riskier state as the passive response to the risk lags more.

Similarly, according to the system (31), we can examine the influence of active guidance on the evolution of NIMBY public opinion. For simplicity, assume that $\varepsilon = 0$, $\delta = 1$, and the values of z^0 are 1000, 105686, and 300000. The results are shown in the following Figures.

Figures 5 and 6 show that when the guidance of the public administrative department is strong, individuals tend not to interact, and the public administrative department can use appropriate positive guidance to move NIMBY public opinion far away from saturation and toward a steadier state. In contrast, if positive, administrative-department-led public opinion is too much or too radical, it will easily arouse public disgust and cause the evolution of

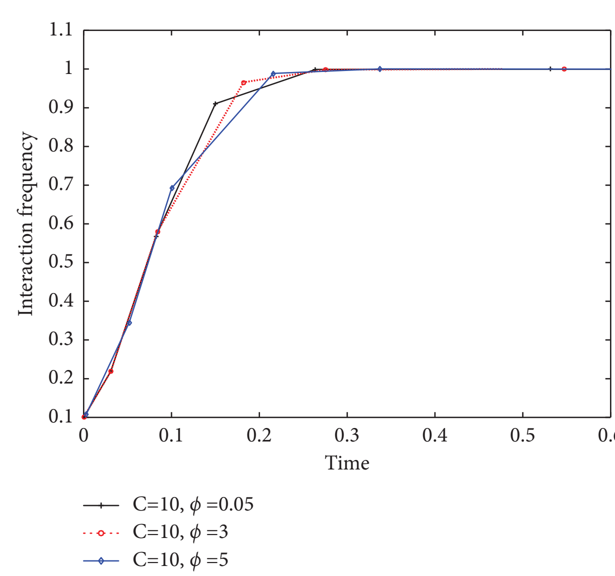

Figure 3: Influence of passive response on the evolution of interaction frequency with weak guidance.

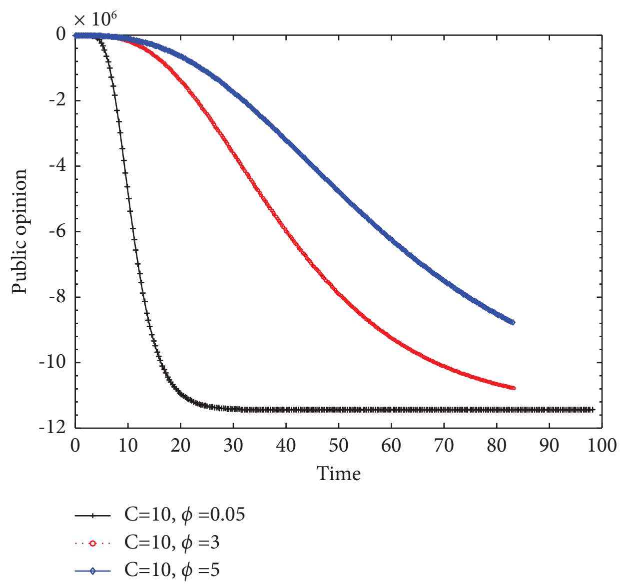

Figure 4: Influence of passive response on the evolution of NIMBY public opinion with weak guidance.

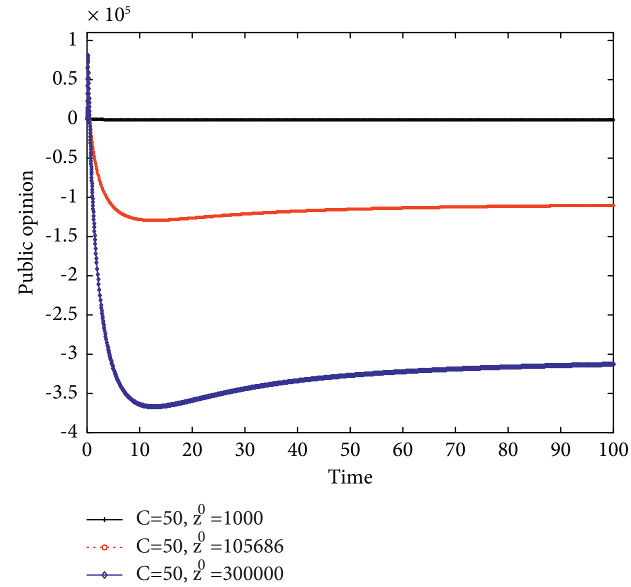

Figure 6: Influence of active response on the evolution of NIMBY public opinion in a scenario with strong guidance.

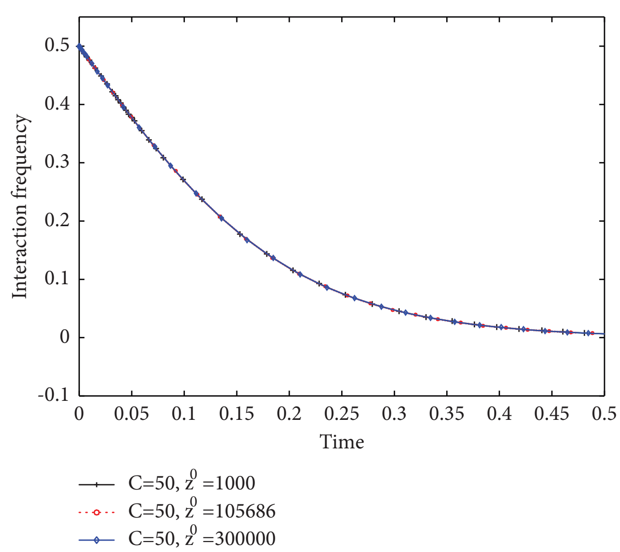

Figure 5: Influence of active response on the evolution of interaction frequency in a scenario with strong guidance.

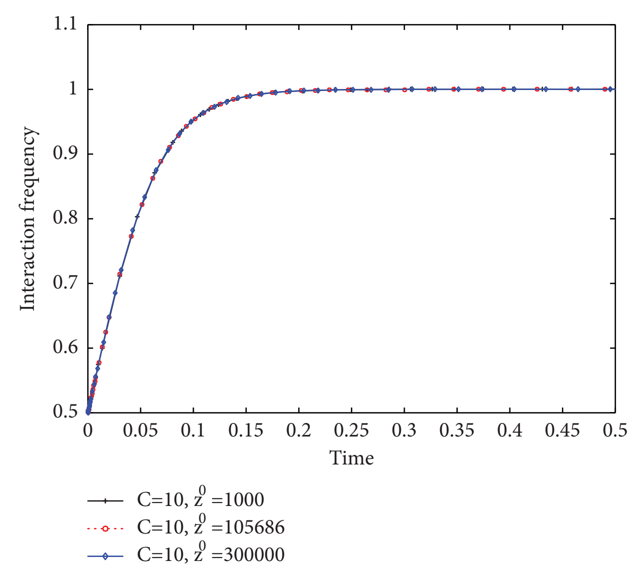

Figure 7: Influence of active response on the evolution of interaction frequency in a scenario with weak guidance.

NIMBY public opinion to evolve into a riskier state. Figures 7 and 8 show that when the public administrative department does not supervise or her supervision is weak, her attempt to eliminate NIMBY public opinion will trigger negative public emotion that will speed up the fermentation and spread of NIMBY public opinion, which eventually leads NIMBY public opinion to rapidly converge into a highly risky state.

Moreover, to investigate the influence of a radical and progressively active response on the evolution of NIMBY public opinion, we conduct another simulation for the case when public guidance is weak and she can properly respect NIMBY public opinion and guide it with a proper strategy. The values of the parameters are determined as follows: $\varepsilon = 0.1$, $\delta = 0.8$, and the initial values of (x, y, z) are chosen as $(0.5, -500, 5000)$ and $(0.5, -500, 500)$. The simulation results are shown in Figure 9. They show that in the case of low or limited supervision, the aggressive and proactive response will restrain the negative side of the public opinion in a small range in the short term, but in the long run, the radical public opinion guidance will cause the negative side of the public opinion to evolve from fluctuating with a small magnitude to fluctuating with a large magnitude, eventually exhibiting periodicity in a larger range. However, the progressively active response will make the negative side of NIMBY public opinion evolve from fluctuating with a high magnitude to fluctuating with a smaller magnitude, eventually evolving to the periodicity being in a small range.

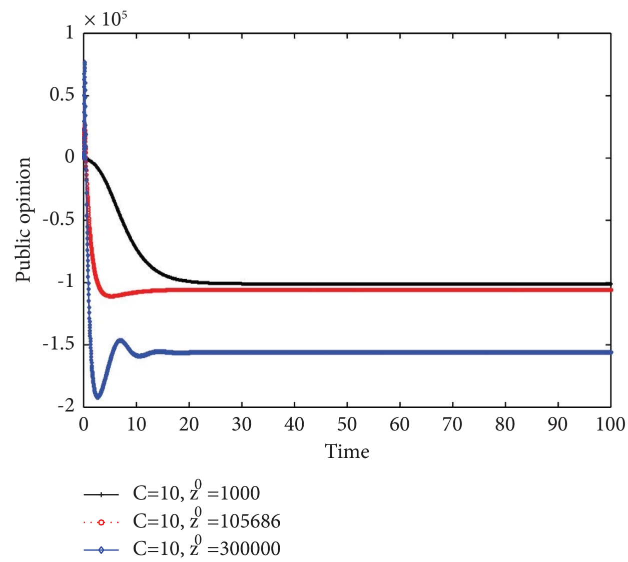

Figure 8: Influence of active response on the evolution of NIMBY public opinion in a scenario with weak guidance.

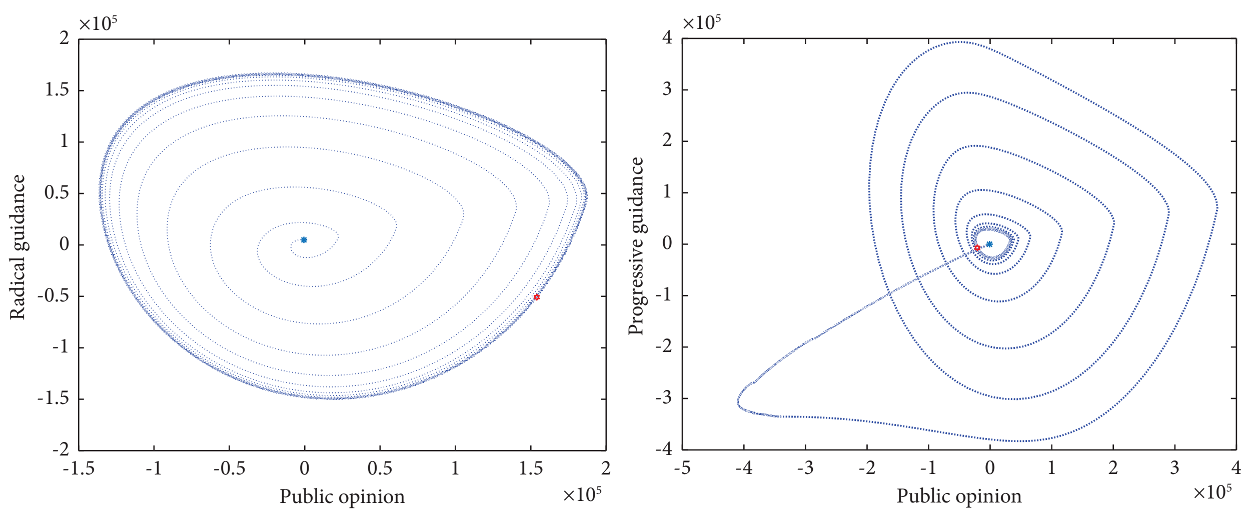

Figure 9: Influence of the administrative-department response on the evolution of NIMBY public opinion with weak guidance: radical response and progressive response.

5. Conclusions and Management Suggestions

As the Internet has become an important medium for public opinion, how to effectively control NIMBY public opinion appears to be very important for the public administrative department to appropriately respond to the public's opinion. This study examines how the interaction between individual perceptions of the potential risk of NIMBY projects and administrative-department-led public opinion affects the evolution of public opinion. The results reveal that the public perception of the risk of NIMBY projects is the internal factor affecting the evolution of public opinion, while public administrative department guidance is the external factor. When there is a large discrepancy in the individual perception of the risk of NIMBY projects, the public administrative department should take an active role to respond timely to the public's opinion, such as by strengthening the tracking and supervision of NIMBY public opinion, to guide NIMBY public opinion to return to rationality. When there is a small discrepancy in the public's perception of the project risk, the public administrative department should impose gradual intervention on the public's opinion and respond to it in a timely and appropriate way.

As for how the public administrative department can control public opinion, the results show the following: (1) When the risk of NIMBY projects is high, the public's opinion can readily form and spread rapidly. In this case, the public administrative department should pay more attention to tracking and supervising individual social communication about the risk of NIMBY projects and should also impose strong punishment on rumor spreaders to mitigate their incentives to share information about the project's risks. This thereby can effectively restrain the generation and spread of public opinion. (2) When the individual interactions regarding the project risk can be better controlled through the public administrative department's intervention, the public administrative department should pay more attention to providing timely and appropriate positive responses to the NIMBY public opinion. It should not only respect the public's willingness to know the project risks but also should reasonably guide the public's objective perception of the potential risks, which can effectively eliminate the negative side of NIMBY public opinion as early as possible. (3) When individuals can frequently share their perceptions of information on the project risks, it is difficult for the public's administrative department to directly control them. In such a case, it is necessary for the public administrative department to properly respect the negative NIMBY public opinion and provide active and relevant guidance. When paying more attention to the NIMBY public opinion, the public administrative department should also enact progressive guidance to provide timely and active responses, thereby limiting the negative NIMBY public opinion and controlling it within a small range.

5.1. Highlights

(1) An evolution model of NIMBY public opinion describing public guidance and individual interactions was constructed.

(2) The evolutionary equilibrium and stability of NIMBY public opinion in different administrative-department-led scenarios were examined.

(3) The evolution of NIMBY public opinion during an antinuclear event in China was analyzed.

Data Availability

All the models and data during this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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