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An Extensive Evolutionary Mental Game Model for the Mandatory Evacuation of Protesters by Police

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ABSTRACT The street protests and other mass demonstrations that have occurred frequently in recent years have resulted in considerable political pressure and have destabilized countries. How governments respond to such emergencies, and whether to evacuate protesters quickly, has been one of the most important public management challenges facing modern governments. In the case of evacuating protesters through police force, issues to consider include the cognitive differences among the conflicting parties and the cost-benefit considerations between the alternative strategies of mandatory evacuation and compromise. In this paper, the evolutionary dynamic of the mandatory evacuation of protesters by police is analyzed by extensive evolutionary game theory. Considering the cognitive differences among the conflicting parties, mental models of the interactions between government officials and protesters are constructed, which can not only avoid the uncertainty of evolutionary equilibrium but also consider the belief learning in the interior of the dynamic stage game. The evolutionary dynamic analysis of the mandatory evacuation of protesters is subsequently performed. To verify the effectiveness of the model set out, a multiagent simulation analysis based on a real case study of the Ningbo PX incident is presented. Furthermore, the decision-making related to police evacuation of protesters is based on the cost-benefit analysis between mandatory evacuation and compromise, the minimal number of police required, and the on-the-spot deployment plans of the police. The analysis shows that when facing protesters marching along a street, the evacuation measures are more effective if the police actions target the first several rows of protesters. However, in the case of protesters gathering near iconic buildings (or surrounding their demonstration leaders), the emergency plan of the mandatory evacuation of the protesters is less effective.

INDEX TERMS Evacuation dynamics, evolutionary game, extensive form game, mandatory evacuation, mental model.

I. INTRODUCTION

Due to the recent global pandemic, a highly unstable socioeconomic environment has emerged [1]. The profound impact of the crisis extends well beyond the economic and financial aspects, as policymakers need to cope with new challenges, such as economic downturns, layoffs, pay cuts, corporate failures, steeply increases in unemployment, and street protests (or demonstrations). Following the global financial crisis in 2008, mass protests against governments spread to many countries around the world, including the anti-government "Red-shirts" in Thailand [2], the so-called "Indignants" in Spain [3], the "Arab Spring" in Arab countries [4], and the Occupy Wall Street (OWS) movement in the U.S. [5]. The most recent mass violent protest took place on January 6, 2021, when a large number of Trump supporters protesting the recent presidential election stormed the U.S. Capitol building and vandalized property. Several people were killed or injured in the attempt to quell the riot. The riots shocked the world and had a very negative impact on the United States. In addition, in recent years, youth-led political protests have taken place in many countries or regions [6]–[10], including

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South Africa, Chile, India, and Hong Kong in China. These actions have caused serious political pressure and instability, and governments around the world are trying to solve these problems. How can governments respond to these emergency situations and evacuate protesters rapidly? This issue has long been a considerable challenge for the public management of modern governments [11]. Social crises, such as mass protests, strikes and riots, not only threaten life and property safety directly but also create a social psychology of fear and insecurity. Such situations threaten governments with a loss of credibility and the risk of destroying basic social values and codes of conduct [12]. When safeguarding citizens' legitimate rights to rally, strike and demonstrate, governments also need to intervene in timely and appropriately ways to avoid violence by irrational protesters. Emergency management and the rapid evacuation of protesters pose a dilemma for governments.

The study of evacuation and pedestrian dynamics is a rapidly developing discipline that studies pedestrian movements and crowd management in public places under both normal and emergency situations. The modeling of evacuation and pedestrian dynamics has increased significantly over the past 10 years. There are many types of literature on the problem of safe evacuation from various places and in different types of accidents, for example, internal structural design safety of public buildings [13], places crowded with people, such as city subway stations and shopping malls [14], and traffic disasters, including those affecting maritime shipping [15], and railway and air transportation [16], [17]. One research approach is to use field surveys and experimental observations to obtain initial data; another approach employs simulation analysis using evacuation simulation software [18], [19]. For example, Alginahi *et al.* [20] introduced the simulation and analysis of crowd evacuation patterns in a large, densely populated building. In general, determining optimal escape routes, decreasing delays and improving the education of people are the three most important issues in crowd evacuation in emergency cases [21].

Street protests (or demonstrations) can be nonviolent or violent; also, they can begin as nonviolent and become violent, depending on the circumstances. Sometimes riot police or other forms of law enforcement are involved. In some cases, this involvement could be an attempt to prevent the protest from taking place at all. In other cases, the presence of law enforcement could be a measure to prevent clashes between rival groups or to prevent a demonstration from spreading and turning into a riot [22]–[25]. There are some studies that have explored these problems by focusing on the classification of protesters. For example, Kwon [26] classified protesters' experiences into five categories, independent, entertaining, reflective, solidary, and distributive, through investigating different clusters involved in candlelight protests in South Korea. Lundberg [27] developed a framework to explore the role that civil society organizations (CSOs) play in counteracting right-wing extremism by considering the distinction between tolerance and intolerance, and active and passive political participation. Through focusing on psychological and behavioral changes, Vestergren *et al.* [28] stated that more precise investigation of the relationship between types of protests, social and psychological processes, and psychological outcomes is needed. Different from traffic accidents or other types of disasters in public places, police evacuation of protesters faces more complex situations. Reynolds-Stenson [29] indicated that the police response to protests against police brutality was considerably more aggressive than that against other protests. Tyler *et al.* [30] tested the effects of perceived injustice on protester behavior and found that the main predictor of violence against police by protesters is the perception that the police unfairly used force on the protesters. Considering the antagonistic contradiction between subject and object perceptions, conflict of interests and object (protesters) activeness, it is obvious that such problems are embodied in the game theoretic framework instead of unilateral optimal problems. The existing optimization literature in the field of social crisis has focused on some problems, including resource allocation [31], [32], information sharing [33], and crisis early warning of terrorist attacks or protests [34]. For example, Daphi [35] investigated the role of protests' spatiality in their transformative influence by using a narrow approach to space. Liu *et al.* [36] studied the law of behavior in the process of group evacuation by considering the overall effect of pedestrians and the micro characteristics of individuals. Qi *et al.* [37] studied the connection between personal online communication data and street protests, believing that potential digital footprints online can reveal human behavior characteristics in the real world. Similarly, Waldherr and Wijermans [38] explored how the use of social media affects the collective dynamics of street protests based on an agency model. D'Orsogna and Perc [39] highlighted that methods of statistical physics may provide a better understanding of criminal activity. Helbing *et al.* [40] discussed different models based on data related to crime, terrorism, and crowd disasters to show that complexity science can contribute to understanding the complexity of social systems.

However, there are few investigations of the problem of mandatory evacuations of protesters. Shall the government satisfy the protesters demands to pay them some form of compensation or attempt to use police force to carry out a mandatory evacuation of the protesters? Once the mandatory evacuation is chosen, how many policemen are required? What kind of practical deployment schemes are needed in special scenarios? Are there any other house rules that policymakers should know before the police start the mandatory evacuation? For improving the governmental early warning and rapid response capabilities, these important theoretical questions need to be answered. This paper is devoted to providing answers to these questions, which can help the government decide whether to evacuate protesters.

As a game theory problem between policymakers and protesters, traditional game theory is limited to the "superrational'' assumption in a fixed environment, which is difficult to apply to the mandatory evacuation problem with bounded rationality, or even the irrational behavior of protesters. Exhibiting rapid growth in the 1990s, evolutionary game theory studies the bounded rational behavior in groups and corresponding course of adaptive learning [41]. Evolutionary game theory provides an appropriate theoretical framework to analyze the emergency handling process of crisis events related to public security, such as mass protests, strikes or riots. For example, Wang *et al.* [42] reviewed the evolutionary game and its cooperation on multilayer networks. Zheng and Cheng [43] studied cooperative behaviors and evacuation efficiency by combining an evolutionary game theoretic approach with a cellular automata model. Guan *et al.* [44] examined the evolution of pedestrian evacuation by considering different human behaviors. As an extension, Guan and Wang [45] further explored the evolution of cooperation in pedestrian evacuation mixed with different individual behaviors by means of a spatial game coupled with a cellular automaton model. Based on an evolutionary game, Huang *et al.* [46] analyzed the behavioral evolution of people being evacuated to a certain extent by introducing the heterogeneous rationality of small groups. Ibrahim *et al.* [47] explored the evolution of potential crowd behavior by simulating the crowd evacuation process under uncertain conditions.

However, there are still some challenges when evolutionary game theory is applied to the mandatory evacuation of protesters. First, different from the normal form stage games in evolutionary game theory, it is more appropriate that the interaction between government officials and protesters be described as an extensive form stage game. Because there are belief differences in a dynamic game, the special ''mental model'', i.e., cognitive rules and behavioral rules, of the players need be predetermined, which is different from the idea of subgame monotonicity that Cressman [48] developed for analyzing evolutionary dynamics in extensive form stage games. Second, in the various payoff scenarios that can be seen as the exogenous institutes, there are several equilibrium results. Under a competitive and communication environment, which equilibrium is more stable? In this paper, following the approach introduced by Aoki [49], we perform an evolutionary dynamic analysis to obtain the multiple equilibriums of the police mandatory evacuation problem. From the viewpoint of comparative institutional analysis [50], game equilibrium indicates some stable institutional models. Therefore, the multiple equilibriums represent different emergency disposal programs competing with each other and continuing to evolve. Third, because of the long-term gradual process of social system evolution, the sudden occurrence, no repeatability and sensitivity of social crisis, the public statistical data regarding social crises are sorely lacking. Thus, in the field of emergency management, utilizing game theory has been a very common way to verify the effectiveness of models set out by the multiagent simulating analysis based on a real case study.

This paper makes a number of contributions to the existing body of knowledge. (1) An innovative framework of structural game analysis for the behavior of the mandatory evacuation of street protesters by police is proposed in the context of extensive evolutionary game theory. (2) Considering the cognitive differences of the conflicting parties, as a new analytical approach, the mental models capturing the interaction between government officials and protesters are built, which avoids the uncertainty of evolutionary equilibrium and incorporates belief learning within the dynamic stage game. (3) From the operational level, the key practical factors affecting the successful mandatory evacuation by the police are deliberated systematically, and a solid countermeasure basis for the behavior of police in mandatory evacuations of street protesters is provided.

The rest of the paper is organized as follows. In Section II, we provide a new analytical framework of mental models for the evolutionary dynamics of mandatory evacuation using an extensive form stage game. In Section III, we perform an evolutionary dynamic analysis of the mandatory evacuation of protesters between two deterministic equilibrium results. Section IV discusses some influencing factors of police evacuation of the protesters. Section V presents a multiagent simulating analysis based on a real case of the Chinese Ningbo PX incident in 2009. Finally, the conclusions are given in Section VI.

II. MENTAL MODELS OF GOVERNMENT OFFICIALS AND PROTESTERS IN STAGE GAMES

In this section, we first present the extensive form game model for the mandatory evacuation of protesters and subsequently discuss the subgame monotonicity in extensive form evolutionary games. In analyzing the course of police emergency dispersal and the mandatory evacuation of protesters, the antagonism of value judgment hidden by the actions of protesters and government officials cannot be ignored. Therefore, by considering the cognitive and behavioral rules of players, we introduce the concepts of ''mental model'' and ''feasible strategies'' into the extensive form game to model the evolutionary processes. The mental model not only avoids the uncertainty of evolutionary equilibrium but also considers the belief learning that takes place in the interior of dynamic stage games.

A. EXTENSIVE FORM GAME MODEL FOR THE MANDATORY EVACUATION OF PROTESTERS

For a two-player extensive form game in Fig. 1, suppose that government official I carries out one particular social economic policy, where government official I alone obtains value V, for example, to maintain their authority, welfare benefits, or rents seeking. However, this exclusive policy undermines the economic interests or development space of opposition group J. If the opposition group keeps silent about the political views or takes peaceful action in a legal way such as winning more future votes or media coverage, the opposition group gains nothing in the current state. If the

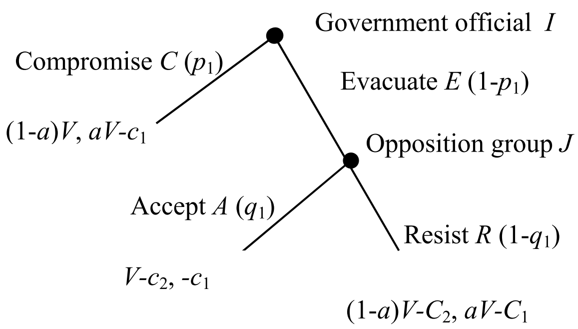


FIGURE 1. Extensive stage game of protester evacuation.

opposition group pushes their supporters to protest against the government policy by a rally, march, or strike, they need to pay organizing cost c_1. If government official proposes a compromise C in the face of the large-scale political pressure of protesters, the two sides can reach a settlement agreement to share value V, assuming that the opposition group's share is aV, where a is defined as the bargaining power of the opposition group. If a government official resorts to the use of police force to evacuate the protesters, the official needs to pay administration cost c_2 to persuade other policymakers to agree to mandatorily evacuate the protesters.

Whether the mandatory evacuation is successful not only depends on the possible reactions of the protesters but also on other complex factors, for example, the number of dispatched police, on-the-spot disposition plans of the police, the natural environment of the location where the incident is taking place, and media coverage. Those influencing factors will be discussed in Section IV. If the police can successfully evacuate the protesters, government officials would continue to enjoy total social value V. Otherwise, government officials will continue to deal with protester resistance. In this case, the protesters will continue to protest for a long time if necessary until they eventually achieve their goals. Based on the Folk Theorem of repeated games [51], any feasible payoff in which Pareto dominates a Nash equilibrium payoff of the stage game will be an equilibrium payoff in the associated T-phases repeated game with sufficiently patient players, that is the discount rate is near 1, $\delta \to 1$. Therefore, the largest feasible payoff of protesters is aV-C_1 when they choose the Resist strategy under the threat of mandatory evacuation. In this case, the protesters have to pay the cumulative resisting costs $C_1 = \sum_{t=1}^{T} {\delta_1}^{t-1} c_1$, and the official undertakes the associate cumulative costs $C_2 = \sum_{t=1}^{T} {\delta_2}^{t-1} c_2$ as the cost of safeguarding stability in China.

If the continuous resistance movement does not pay for either the protesters or the official, although the one-shot administration cost c_2 is not very high for the official, then the subgame perfect Nash equilibrium path in Fig. 1 is (Evacuate, Accept) with the outcome of (V-c_2, -c_1).

B. SUBGAME MONOTONICITY IN EXTENSIVE FORM EVOLUTIONARY GAMES

As Friedman pointed out in his report titled "Economics (and Finance) as an Evolutionary Game" at the Santa Fe Institute Workshop in 2000, there are some advanced problems in the field of evolutionary game theory, in which the second open problem is extensive form stage games. The typical Hawk-Dove game model of evolutionary game theory belongs to the static stage game, where both players take actions simultaneously or take actions in turns, but a player is unable to observe the other's action. If the extensive form stage game is considered, the problem becomes more complicated. Two different types of learning process are included: the first is that the late-mover's belief should be updated after observing the first-mover's action in the interior of the dynamic stage game; the other is that an anonymous player imitates the more successful strategy after observing the relevant strategies' payoffs in the previous period, when he/she randomly encountered the other player, which is the intergeneration learning process.

Along with the thought of transforming an extensive form game into a strategic/normal form game, Cressman [48] developed the theory of subgame monotonicity for extensive form games to a model evolutionary process. For the example of an extensive form game of protester evacuation in Fig. 1, it can be transformed into the strategic form game as shown in Table 1. Under the assumption of relative payoffs, (E, A) and (C, R) are both pure strategy Nash equilibria, the former being a subgame perfect Nash equilibrium. The latter is a weak Nash equilibrium because of the opposition group's nondominant strategy given the opponent's "Compromise".

TABLE 1. Strategic stage game of protester evacuation.

		Opposition group J	
		Accept A	Resist R
Government official I	Compromis C	(1-a)V, aV-c_1	(1-a)V, aV-c_1
	Evacuate E	V-c_2, -c_1	(1-a)V-C_2, aV-C_1

According to the typical replicator dynamic function, if p_i is the frequency of individuals in the population of government official I who use the ith pure strategy e_i in strategic form and q_j is the frequency in the population of opposition group J who use the jth pure strategy e_j, the continuous-time replicator dynamic [51] is

$$dp_i/dt = p_i \left[\pi_1(e_i, q) - \pi_1(p, q)\right]$$
$$dq_j/dt = q_j \left[\pi_2(p, e_j) - \pi_2(p, q)\right]. \quad (1)$$

where $\pi_i(p,\ q)$ is the expected payoff to player i between mixed strategies p and q of two populations, respectively.

From Equation (1) and Table 1, the replicator dynamic function of the opposition group that has taken the Accept strategy is

$$dq_1/dt = q_1(1-p_1)(1-q_1)[-c_1-(aV-C_1)] = q_1(1-p_1)(1-q_1)\left(\sum_{t=2}^{T}\delta^{t-1}c_1 - aV\right). \quad (2)$$

Because of $\sum_{t=2}^{T}\delta^{t-1}c_1 > aV$, the strategy of "Accept" is the weak dominant strategy for opposition group J, and the frequency q_1 is strictly increasing along interior trajectories for the replicator dynamic, as long as not all government officials adopt the Compromise strategy, $p_1 \neq 1$.

Similarly, for government official I, the replicator dynamic function of the group that has taken the Compromise strategy is

$$dp_1/dt = p_1(1-p_1)\left[\begin{array}{l}(1-a)V-(V-c_2)q_1- \\ ((1-a)V-C_2)(1-q_1)\end{array}\right]. \quad (3)$$

Next, we discuss the Evolutionary Equilibrium. According to the two-player replicator dynamic functions (2) and (3), if $(1-a)V < (V-c_2)q_1 + ((1-a)V-C_2)(1-q_1)$, that is, $\frac{C_2}{aV-c_2+C_2} < q_1 < 1$, the frequency p_1 is strictly decreasing. Combining the increasing frequency $dq_1/dt > 0$ with the decreasing frequency $dq_1/dt < 0$, the only Evolutionary Equilibrium (EE) is the strategies profile (Evacuate, Accept), which is also a subgame perfect Nash equilibrium.

If $0 < q_1 < \frac{C_2}{aV-c_2+C_2}$, the frequency p_1 is strictly increasing until reached at $p_1 = 1$. In this case, the frequency q_1 is changeless according to Equation (3). Thus, the Evolutionary Equilibrium is located in an interval of the boundary line, which is $p_1 = 1$ and $0 < q_1 < \frac{C_2}{aV-c_2+C_2}$.

Cressman [48] defined the special invariant surface in Equation (4).

$$W = \left\{(p,q) \in \Delta^2 \times \Delta^2 \middle| q^* = \frac{C_2}{aV-c_2+C_2}\right\} \quad (4)$$

is called the Wright manifold, which can keep the monotonicity of the overall dynamics and of the subgame dynamics.

Definition 1: The Wright manifold is defined as the set of completely mixed strategies for which the expected strategy used by an individual in subgame u does not depend on what choice was used at information sets that are not relevant for u.

To analyze extensive form evolutionary games, the key consideration is determining the population weighted average payoff. Cressman [48] defined the concept of Wright manifold that can determine the monotonicity of the subgame dynamics. This analytical method is based on the general extensive form game being transformed into a normal form game that has no interior learning processes in one generation and later employs the intergeneration evolutionary analysis. This method belongs to the static analysis method because the interior learning process in the dynamic form stage game is neglected. The method is similar to the concept of Evolutionary Stable Strategy, which determines the stability of evolutionary results by the static utility function but not the replicator dynamic. In the following section, we shall put forward other analytical methods, where the concepts of "mental model" and "feasible strategy" are introduced. The basic idea can be described as that the alternative set of strategies of the population weighted average payoff can only be those feasible strategies among the existing mental models of the players.

C. MENTAL MODELS OF PLAYERS IN EXTENSIVE FORM EVOLUTIONARY GAMES

To determine the population average payoff in the last period, we introduce the concepts of "mental model" and "feasible strategies" into the extensive form game to model evolutionary processes. Given the relevant cognition rule and behavioral rule of players, the first type of learning process, that is, the late-mover's belief renewal in the interior dynamic stage game, can be described in a precise way. More specifically, the alternative strategies set to confirm the population average payoff can only be the relevant feasible strategies among the player's existing mental models.

Social crisis is defined as an event that brings a serious threat to basic social values and codes of conduct [52]. When society is experiencing a social crisis, there is a serious antagonism of value judgments concealed behind the behavior conflict between government officials and protesters, which differs from traditional game theory with its basic hypothesis of "common knowledge". To analyze the course of police emergency dispersal and the mandatory evacuation of protesters, the new analytical paradigm of "external environment–cognitive rule–behavior rule" should be taken into consideration, that is, the "mental model" of government officials and protesters should be considered. The concept of "mental model" has its origin in the field of cognitive psychology, which is a mental mechanism for the purpose of describing the cognitive system objectives and format, explaining the system's function, observing the system's current state, and predicting the future state of the system [53]. Aoki [49] adopted this concept to explain the derivation, evolution, transition and diversification of human social systems. In this paper, the differences of cognitive structure and decision-making behavior between government officials and protesters are defined (or distinguished) through building their "mental models". According to Comparative Institution Analysis Theory [49], we define the concept of "mental model" as follow:

Definition 2: Mental model (or mental procedure) is defined as the individual programming decision-making process or cognitive process, which includes two types of rules: cognitive rule and decision rule.

Once the opposition group turns to street protests outside the system, herd mentality and irrational behavior appear in the collective actions of the protesters. When government resorts to police evacuation of the protesters, it may further cause the protesters to adopt actions of resistance until they reach their goals. The phenomenon can be described by such theories as the altruism utility function [54] of opinion leaders, the reciprocal utility function [55] between police and protesters, and rank-dependent utility theory [56] to explain protesters' emotions. The protesters' cognitive structure and action decision-making, or the outcome (aV-c_1, $(1$-$a)V$) of the path (Compromise, Resist), are referred to as the ''P-mental model''.

In the case of a social crisis, government officials are concerned about how to avoid unfavorable consequences and to maintain the government's image and efficiency. When government official i faces the emergency of a demonstration or rally, the official tends to resort to police evacuation of the protesters in order to maintain vested interests and conceal the underlying problems and anticipates that the protesters will have to accept the mandatory evacuation in the face of a powerful police deterrent. In the above cognitive structure of the governing group, government official i would resort to police evacuation of the protesters. Therefore, the new equilibrium path of the extended game in Fig. 1 is (Evacuate, Accept), and the equilibrium outcome is (V-c_2, -c_1), where government official i should obtain more payoffs than in the other Nash equilibrium path (Resist, Compromise). The cognitive structure and action decision-making model of a government official resorting to police to evacuate protester is called an ''E-mental model''.

Although the value judgment has conflict, the mental models of the two parties are the ''common knowledge''. Thus, through the concept of mental models embedded into an extensive form evolutionary game, the realized possibility of various paths that should decide the population average payoff is neither the strategy profile in a normal form game nor in the Subgame Perfect Equilibrium in the extensive form game but is instead limited to the finite strategies set among mental models of the two parties. These finite strategies set among the mental models of the two parties are defined as ''feasible strategies'' as follows.

Definition 3: Feasible strategies are defined as a set of strategies that can be arrived at in an extensive form game, according to the relevant mental models of all the parties.

The new analytical method of ''mental models'' and ''feasible strategies'', applied into an extensive form game, not only considers the belief renewal in the interior learning process that embodies a player's mental model but also avoids the equilibrium indeterminacy that embodies the limited feasible strategies.

For the extensive form game of mandatory evacuation for protesters in Fig. 1, the feasible strategies include {compromise} in the government official's mental model and {evacuate, accept} in the opposition group's mental model, which are also two Nash equilibriums in the normal form game as presented in Table 1.

III. EVOLUTIONARY DYNAMIC ANALYSIS OF MANDATORY EVACUATION FOR PROTESTERS

In this section, we derive the equilibrium outcomes of the police mandatory evacuation for protesters based on the mental model and replicator dynamic function. Next, the equilibrium evolution among different groups interaction is analyzed and the necessary condition for mandatory evacuation is concluded.

A. EQUILIBRIUM ANALYSIS OF MANDATORY EVACUATION BASED MENTAL MODEL

Given the mental models and relevant feasible strategies of the mandatory evacuation in Fig. 1, the replicator dynamic function of the opposition group with the ''P-mental model'' taking the Accept strategy is

$$dq_1/dt = q_1 \begin{bmatrix} (-c_1) - (-c_1)(1-p_1) \\ -(aV - c_1)p_1 \end{bmatrix} = p_1 q_1(-aV) < 0, \tag{5}$$

where the average payoff of the opposition group in the previous period can be calculated as the multiplication of the payoffs of feasible strategies and their relevant probabilities.

According to Equation (5), the action of opposition group J with the ''P-mental model'' should converge to ''Resist''. Thus, one equilibrium outcome of mandatory evacuation for protesters is (aV-c_1, $(1$-$a)V$) that corresponds to the path of (Compromise, Resist).

Similarly, for government official I with the ''E-mental model'', the replicator dynamic function taken the Compromise strategy is

$$\begin{aligned} dp_1/dt &= p_1 \left[(1-a)V - (1-a)V \cdot p_1 - (V - c_2)(1-p_1)\right] \\ &= -p_1(1-p_1)(aV - c_2) < 0. \end{aligned} \tag{6}$$

According to Equation (6), the action of government official I with the ''E-mental model'' should converge to ''Evacuation''. Thus, the other equilibrium outcome of mandatory evacuation for protesters is (V-c_2, -c_1) that corresponds to the path of (Evacuate, Accept).

Based on the players' mental models and the relevant strategy selection, two equilibria exist in their beliefs separately. However, along with the interaction between the two parties, which one equilibrium should be the ultimate stability? Answering this belongs to the problem of equilibrium evolution, which is discussed in the following section.

B. EQUILIBRIUM EVOLUTION AMONG DIFFERENT GROUP INTERACTIONS

When government officials resort to police evacuation of the protesters, social conflicts generally occur because of the differences of mental models and benefit objectives. In the case of a social conflict, there is a significant clash of values and cognition concealed beneath the surface of the conflict behavior. Even if ''common knowledge'' is the basic hypothesis in traditional game theory, it cannot be ignored that the differences of cognitive structures and decision-making behavior, i.e., the mental model, lies between government officials and protesters. In the case of social conflict settlement, both sides are learning by observing in the process of interaction with others. Eventually, both sides will reach a consensus, that is to say, a new stable equilibrium will be formed. Many theories are available to explain this learning phenomenon, for example, evolutionary games [57], hyper games [58], and even repeated games. In this paper, we consider the best response model introduced by Matsui and Okuno-Fujiwara [59], in which various specific cultural conventions and traditions interact with each other with certain probabilities.

We define several parameters in the best response model when police and protesters randomly confront each other in the process of a mandatory evacuation. The ratio of dispatched police with E-mental model to the on-the-spot total population is defined as k. The encounter probability between police and protesters is shown in Table 2, where the row player encounter the column player. Clearly, the players with the E-mental model as shown in the second column have proportion k of all the people in the case, and the players with the P-mental model in the third column have therefore a proportion of (1-k). Define β as the corresponding degree of police control of protesters, which depends on the police on-the-spot disposition plans. When $\beta = 0$, the police are completely unable to reach the location. When $\beta = 1$, the police are able to reach the location and are fully operational.

TABLE 2. Encounter probability of government officials and protesters.

Players N_i	Encountered other players N_{-i}	
	E-mental model	P-mental model
E-mental model	k	$\beta(1 - k)$
P-mental model	βk	$1 - k$

Now, we analyze the best response dynamics of government officials with the E-mental model and protesters with the P-mental model. When government officials resort to police evacuation of the protesters and anticipate success, i.e., the Evacuate strategy, the expected payoff of government officials with the E-mental model is

$$u_{EE} = (V - c_2) \cdot k + ((1 - a)V - C_2) \cdot \beta(1 - k). \quad (7)$$

When government officials decide to "Compromise", the expected payoff of the government is

$$u_{EC} = (1 - a)V. \quad (8)$$

Under the condition $u_{EE} > u_{EC}$, the strategy Evacuation becomes the government official's best response. Therefore, we obtain the following inequality

$$\beta > \frac{(1 - a)V - (V - c_2) \cdot k}{((1 - a)V - C_2) \cdot (1 - k)}. \quad (9)$$

When opposition group j takes the Accept strategy, the expected payoff of the opposition group with P-mental model is

$$u_{PA} = -c_1. \quad (10)$$

When opposition group j takes the Protest strategy, its expected payoff is

$$u_{PP} = (aV - C_1)\beta k + (aV - C_1) \cdot (1 - k) \quad (11)$$

Under the condition $u_{PA} > u_{PP}$, the strategy Accept becomes the best response of the opposition group. Thus, we obtain the following inequality:

$$\beta > \frac{(aV - c_1) \cdot (1 - k) + c_1}{(C_1 - aV)k}. \quad (12)$$

According to Equations (9) and (12), the successful mandatory evacuation, which means the strategies profile {Evacuate, Accept} becomes the best response of both parties, and depending on the payoff parameters, the proportion of police k and control degree β. Thus, we can reach the following conclusion.

Conclusion 1 (Necessary condition for mandatory evacuation): *Whether the police evacuation of the protesters succeeds depends on the cost-benefit of different strategies adopted by the government officials and the protesters, the proportion of police, and the degree of on-the-spot police control (emergency plan).*

IV. INFLUENCE OF FACTOR ANALYSIS OF SUCCESSFUL MANDATORY EVACUATION

In this section, we deliberate the influence of some important practical factors on the police successful mandatory evacuation for the protestors, including the cost-benefit balance of different strategies, the proportion of police, and the on-the-spot disposition plans of the police.

A. COST-BENEFIT OF DIFFERENT STRATEGIES

Even if there are certain irrational behaviors of the protesters, the primary motivation of the conflicting parties is driven by different economic interests, besides other social and psychological factors such as identifications, efficacy, emotions and feelings of injustice [60]. Moreover, other social and psychological factors, e.g., emotions or reciprocity, can be considered by some extended utility functions. By rational analysis, both government officials and protesters consider the optimal strategy profiles to maximize their own payoffs (or risk neutral utility functions). Clearly, the payoffs of different strategies directly affect the corresponding strategy profiles, but only the strategy profile of (Evacuate, Accept) equates to a mandatory evacuation of success.

According to equations (9) and (12), we obtain the equilibrium evolutionary phase diagram of government officials resorting to police evacuation of the protesters (Fig. 2). In Fig. 2(a), the upper part of the center region represents government officials adopting the Evacuate strategy and protesters adopting the Accept strategy. Therefore, the mandatory evacuation achieves success. However, in Fig. 2(b), this region disappears, which means that the mandatory evacuation is a failure.

Now we evaluate the relative position of critical points A and B. The boundary functions of different basins

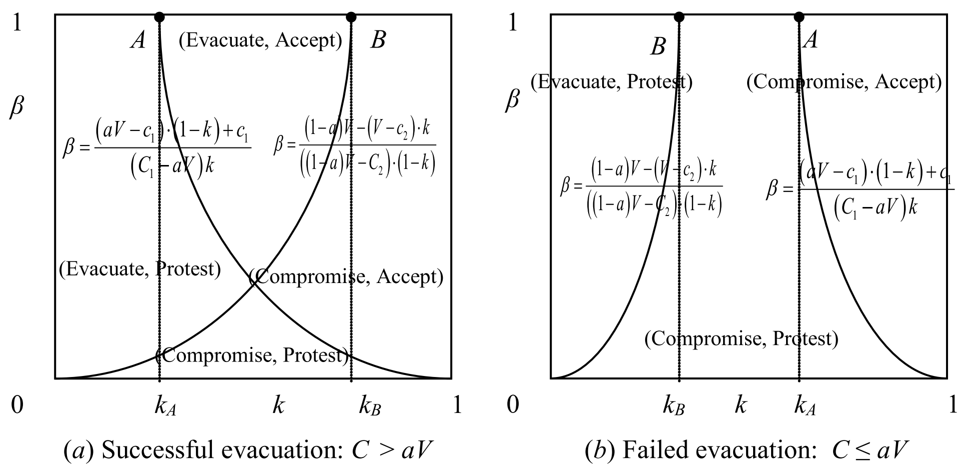


FIGURE 2. Equilibrium evolutionary phase diagram of police evacuating protesters. Note that the mandatory evacuation succeeds in Fig. 2(a) but fails in Fig. 2(b).

of attractions are $\beta = \frac{(aV-c_1)\cdot(1-k)+c_1}{(C_1-aV)k}$ and $\beta = \frac{(1-a)V-(V-c_2)\cdot k}{((1-a)V-C_2)\cdot(1-k)}$. When $\beta = 1$, we obtain the x-axis of critical points A and B:

$$k_A = \frac{aV}{C_1 - c_1}, \quad k_B = \frac{C_2}{aV + C_2 - c_2}. \tag{13}$$

In Fig. 2(a), when $k_B > k_A$, we can easily obtain the following approximate necessary condition of a successful mandatory evacuation:

$$1 > \frac{aV}{C_1 - c_1} + \frac{aV - c_2}{aV + C_2 - c_2} > \frac{aV}{C_1 - c_1} + \frac{-c_2}{C_2 - c_2}. \tag{14}$$

For convenience, we suppose that the stage costs and discount rates of both parties are equal to each other, $c_1 = c_2$, $\delta_1 = \delta_2$; therefore, the simplified necessary condition of a successful mandatory evacuation is shown as

$$C > aV. \tag{15}$$

Only if the cost of sustained protests C_1 or C_2 is greater than the tradable benefit of the opposition group aV is it then possible to accept the mandatory evacuation of the protesters. Specifically, this includes the lower bargaining power of the opposition group, the smaller total value V competed by both parties, and the higher organizing and sustainable cost C_1 or C_2 of the government officials and the protesters.

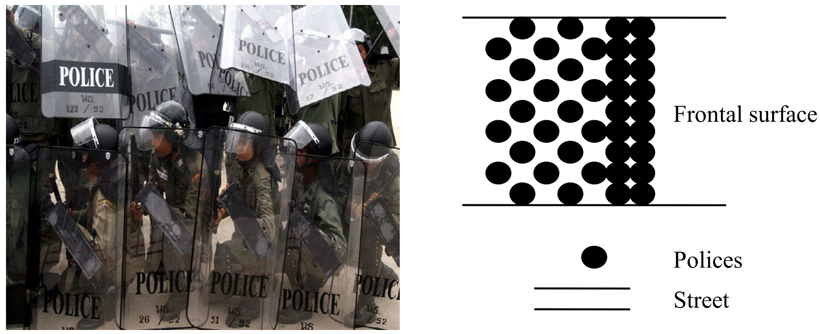
B. PROPORTION OF POLICE

Under the assumption that government officials have enough policemen to be sent to the scene, there will be an optimal range of the number of policemen. On the one hand, in order to force the protesters to retreat, the minimum efficient size of the police force must be satisfied; on the other hand, government officials must be careful and prudent in the use of police force to avoid creating a negative image of police abuse depriving the opposition group of their basic right to protest at rallies and demonstrations. According to the condition of a successful evacuation in Fig. 2(a), the proportion of dispatched police k should be between the critical points k_A and k_B. If the proportion of police k is lower than the lower limit $k_A = \frac{aV}{C_1 - c_1}$, then the protesters might go beyond the police lines and the situation might worsen. For example, the riots in Shishou, China, which took place from June 17 to 20, 2009, is a typical case of an unsuccessful evacuation. Because the local government officials gradually increased the size of the police force from surrounding urban and rural areas to try to calm down the protesters, more protesters spontaneously gathered and confronted the police, with the number of gathered protesters peaking at approximately 70,000 on the scene [61].

When government officials determine the number of police to be dispatched, they first need to determine whether or not the protesters would be unlikely to accept a mandatory evacuation, that is to say, the cost of sustained protests C_1 or C_2 is greater than the tradable benefit aV in formula (15). Second, the number of dispatched police should lie between the critical values of k_A and k_B, where $k_A < k < k_B$.

C. POLICE ON-THE-SPOT DISPOSITION PLANS (EMERGENCY PLANS)

A high level of uncertainty is one of the main characteristics of street protesters. The Tunisian "Jasmine Revolution" was caused by a college graduate street vendor who committed an act of self-immolation, after which demonstrations quickly spread to other Arab countries. Considering the low frequency, fuzziness and uncertainty of the information, as well as the serious future uncertainty of street demonstrations or riots, scenario analysis is the appropriate method to analyze such a problem. Scenario analysis is a process analyzing possible future events by considering alternative possible outcomes. Thus, scenario analysis does not try to show only one possible future outcome. Instead, it presents several alternative possible future developments. Consequently, a scope



(*a*) Case of police deployment (Thailand) (*b*) Model of police disposition

FIGURE 3. **Deployment of police evacuating protesters. The density of riot police saturates in the first two rows and these police constitute the frontal surface that directly encounters the protesters. Source: http://news.163.com/10/0313/18/chmetcnvUnitNamemSourceValue61HasSpaceFalseNegativeFalseNumberType1TCSC061M4SP33000146BD.html.**

of possible future outcomes will be provided. We obtain not only the outcomes but also the development paths leading to these outcomes [62]. With the development of digital technology and video surveillance systems, the collection, observation, testing, and processing of data and the estimation of the crowd density and movement become more convenient. Some literature suggest pixel-based image processing methods to determine the population density in subways, shopping malls, supermarkets, schools, railway stations, and other places with high pedestrian flow [63]. However, for the game theoretical problem of mandatory evacuation of the protesters, more uncertainty comes from the endogenous uncertain strategies in the confrontation processes. Even if the information derived from video surveillance systems could effectively reduce objective uncertainty, such as the density and motion of the protesting crowds, we are more interested in the on-the-spot disposition plans and the number of dispatched police according to the gathered information regarding the characteristic of protesters.

When government resorts to police evacuation of the protesters, in addition to the number of dispatched police, another major problem is the police on-the-spot disposition plans which determine the degree of police control of the situation (β). In the following subsections, we analyze the effects of different police on-the-spot disposition plans on the degree to which the situation is controlled under two different demonstration scenarios. One is the demonstration scenario of marching along a street, for example, the anti-government ‘‘Red-shirts’’ in Thailand and the riots in Greece; and the other is the scenario of a rally gathering near some iconic buildings or around some opposition leaders, such as the Zuccotti Park in the Occupy Wall Street movement, or the Yonglong Hotel in the Shishou incident in China.

1) POLICE DEPLOYMENT PLANS

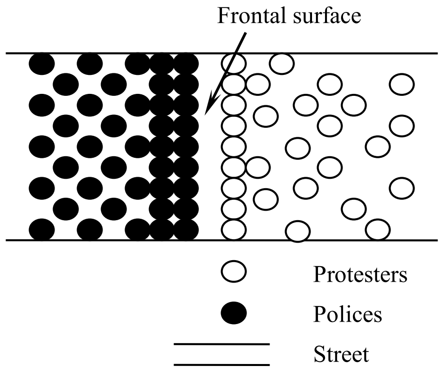
In the case of the mandatory evacuation of protesters, the riot police in the first two rows usually use police shields to build a defensive wall in order to avoid any casualties caused by protester attacks. The police in the first row crouch on the ground to protect the lower part of their bodies and the second row stands firm to protect their upper bodies. Therefore, the density of riot police saturates in the first two rows. This approach can be seen in Fig. 3(a), where the riot police participate in an anti-riot exercise in Narathiwat province in southern Thailand on March 13, 2010. According to existing research, the biggest possible crowd density is approximately 8 to 9 people per square meter, in general. Considering Chinese physiological characteristics, this value can be equal to 9 people per square meter [64]. The police located in the following rows always keep a close formation to avoid being isolated when facing protester attacks. There are some research studies on evacuation and pedestrian dynamics in disaster incidents that discuss the relationship between population movement speed and crowd density [65]. However, for the problem of police evacuation of the protesters, the density of police formation should satisfy the requirement of safeguarding their own safety. Thus, the density shall not change significantly when the movement's speed changes. According to Au *et al.* [66], the recommended density in an average situation is approximately 1.53 to 2 people per square meter. In Fig. 3(b), the police located in the first two rows constitute the frontal surface that directly encounters the protesters.

It should be noted that the police deployment formation ideally takes a tight linear formation, not a semicircular formation, to confront the protesters. The objective of government officials is to evacuate the protesters in the opposite direction, but not to encircle and arrest any protesters.

2) PROTEST MARCH SCENARIO

In the scenario of a demonstration march, the density distribution of the protesting crowd is characterized by the protesters located in the first row in a situation of close formation. On one hand, the first row of protesters is under the greatest pressure of mandatory evacuation; on the other hand, protesters in the first row must stay very close together to avoid being divided, surrounded, or isolated. Because the protesters lack formal organization and discipline, the crowd behind the first row gradually becomes more randomly positioned. This can be seen in Fig. 4(a), where

(a) Case of protesters demonstration (Greece)



(b) Model of protesters demonstration

FIGURE 4. **Crowd density distribution in the protester demonstration scenario. The protesters located in the first row are in close formation and the crowd behind the first row gradually becomes more randomly positioned. Source: http://www.reuters.com/article/idUSTRE61N20820100224.**

the police dispelled the protesters in Greece on March 16, 2010. According to Au *et al.* [63], the recommended police density in a relatively unrestricted situation is approximately 0.83 people per square meter.

According to the critical data of population density under different conditions, because the protesters located in the first row ($r = 1$) directly confront the police, which means $\beta = 1$, the protesters should stay close together to reach the largest possible population density of 9 people per square meter [64]. Because protesters in the following rows are rather unorganized (where $\beta = 0$), the protester density distribution is approximately 0.83 people per square meter [66]. We assume that the density distribution of protesters in each row follows an exponential distribution given below:

$$f(N) = 0.83 + 22.2 \exp(-r), \quad (16)$$

where N is the protester number, *f(N)* is the density of per square meter, r is the row number in the protester crowd, and $f(N)_{t>4} = 0.83, f(N)_{t=1} = 9$.

We show the frequency distribution of formula (15) in Fig. 5. Clearly, for the protest march scenario, it is more favorable that the government resorts to police evacuation of the protesters because the police on-the-spot deployment has a greater degree of control of most of the protesters.

3) RALLY SCENARIO

In the protester rally scenario, the density distribution of the gathered protesting crowd is a concentric distribution, which centers on an iconic building or around several demonstration leaders. The population density gradually decreases from inside to outside. When police attempt to evacuate the crowd, the density of protesters begin to increase in the frontal surface where the two sides clash. That can be seen in Fig. 6(a), where tens of thousands of protesters had gathered around the Yonglong Hotel in Shishou city in China from June 17 to 20, 2009. After repeated consultations between local government officials and the families of the dead, the families agreed to

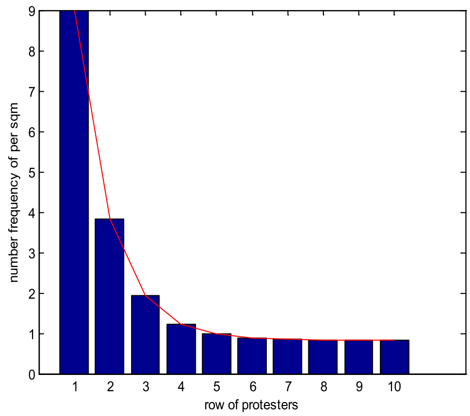


FIGURE 5. **Crowd frequency distribution in the scenario of protest march.**

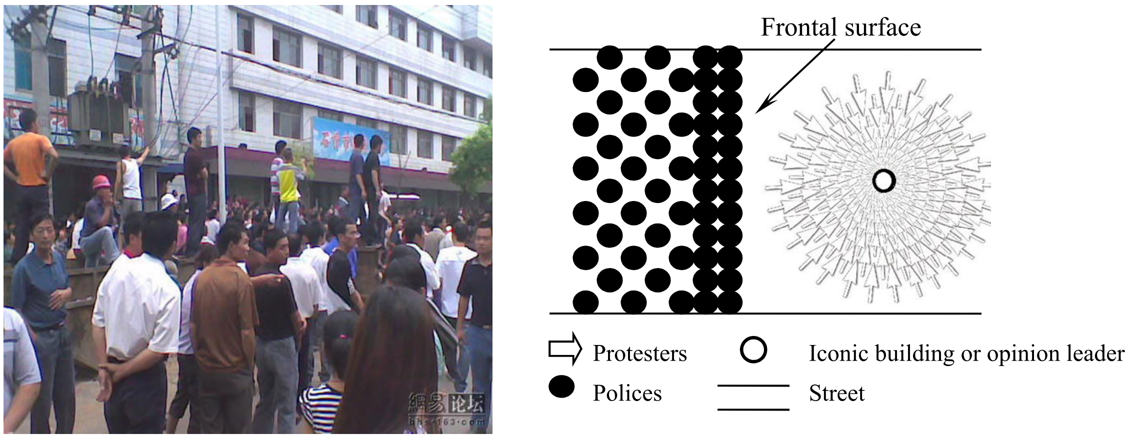
carry the bodies to a funeral home, and the crowd finally agreed to withdraw.

To simplify the analysis, we assume that the gathered protesting crowd forms a circular distribution with a homogeneous population density (Fig. 7(a)), where r is the radius of the circle, and d is the intervention degree of the police or the height of the arch. We further define the police intervention intensity *d/r* as the ratio of intervention degree d to radius r. When $d/r = 1$, the police can control the core area of protesters. The degree of police control of the protesters β is equal to the ratio of the effectively controlled number at the frontal surface to the total protesters, that is, the ratio of the arch area to the circle area.

According to the left panel (a) in Fig. 7, we obtain the analytical relationship between police intervention intensity *d/r* and the degree of control β as the following:

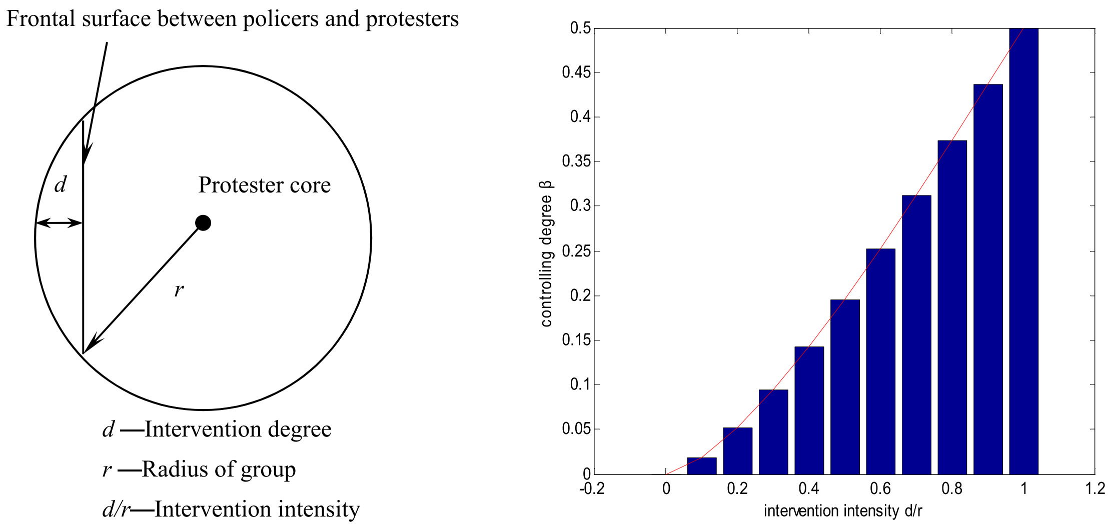
$$\beta = [2 \arccos(1 - d/r) - \sin(2 \arccos(1 - d/r))] / 2\pi \quad (17)$$

We can show the relationship between d/r and β in the right panel of Fig. 7. When government officials take the intervention measures to carry out a mandatory evacuation of



(*a*) Case of protesters rally (China) (*b*) Model of protesters rally

FIGURE 6. Crowd density distribution in the protester rally scenario. The density distribution of the gathered protesting crowd is a concentric distribution, but the density gradually decreases from inside to outside. Source: http://free.21cn.com/newbbs/mainframe.jsp?url=/forum/bbsMessageList.act?bbsThreadId=2646862.



(*a*) Mathematics model of protesters rally (*b*) Relationship diagram between d/r and β

FIGURE 7. Police intervention intensity *d/r* in protester rally scenario.

the protesters, this only has the direct effect on the periphery of the gathered protesters. Because of the low ability to control the events, the effectiveness of the evacuation measures is very limited at this time, unless the police increase the intervention intensity to reach the center area of protester crowd.

Comparing the two scenarios of protest marching along a street, and a rally gathering at some iconic buildings (or around a few demonstration leaders), we arrive at the following conclusion.

Conclusion 2 (Effectiveness of emergency plans): *In the scenario of a protest marching along a street, the implementation effect will be better if the police aim at the first few rows of the protesters when they take evacuation measures. In the scenario of a demonstration at iconic buildings (or around the demonstration leaders), the emergency plan of a mandatory evacuation will have an inferior effect where the police only attempt to control a few protesters on the periphery. In this case, the government should consider other channels to resolve the problems, such as compromise or negotiation.*

V. MULTI-AGENT MODELING AND SIMULATION BASED CASE OF NINGBO PX INCIDENT IN 2009

Situations of social crisis, such as street protests or demonstrations, have social sensitivity, are not repeatable, and are characterized by suddenness and high uncertainty, the relevant data is difficult to obtain. The existing literature has often used numerical analysis [31], [34], case analysis [67] and social simulation [68]–[70] to test the accuracy and applicability of mathematical models to analyze social crises, including mass incidents, emergency evacuations [68], "not in my backyard'' incidents [67], and acts of terrorism [31], [34]. Considering the shortage of case analysis for situations with low recurrence, Eisenhardt [71] advises that there need to be at least four or more cases, or some smaller cases embedded into a larger case, in order for the case analysis method to be applied to construct a new theory. Social crisis is difficult to directly observe and investigate because of its social sensitivity and non-repeatability; therefore, the multiagent social simulation analysis of social crisis is generally used in the field of emergency management. Since the 1990s, the agent-based modeling and simulation technology is widely applied in various domains such as society, economy, and population dynamics. A multiagent simulation model consists of a number of software objects, the ''agents'', interacting within a virtual environment. The agents are programmed to have a degree of autonomy, to react to and act on their environment and on other agents and to have goals that they aim to satisfy. With such a model, it is possible to initialize the virtual world to a preset arrangement and subsequently let the model run and observe its behavior. While most agent-based simulations have been created to model real social phenomena, it is also possible to model situations that could not exist in our world in order to understand whether there are universal constraints on the possibility of social life, which can compensate for the lack of case analysis [72]. In this section, we apply the multiagent modeling and simulation technology under the platform of NetLogo to simulate the various evolutionary results under multiple scenarios, where the case of police mandatory evacuation for protesters originates in the famous Chinese Ningbo PX incident in 2009.

A. THE NINGBO PX INCIDENT OF 2009

In recent years, mass incidents against the PX project broke out in many cities in China, including Dalian, Xiamen, and Ningbo. On October 22, 2012, more than 200 villagers from Zhenhai town in Ningbo city collective appealed to the Zhenhai District Government for help and blocked the road at a traffic intersection to protest the location of a new chemical enterprise (PX project) too close their village. On October 26, 2012, 5,000 citizens took part in the demonstrations, but police and special police made plans to conduct a mandatory evacuation of the protesters. The total investment estimation of the PX project is approximately 55.873 billion Chinese yuan (RMB). According to the requirements of Environmental Protection Departments, the PX project implements the most stringent emission standards, where the total input of environmental protection is approximately 3.6 billion RMB. Twenty villages should be preserved and transformed into an ecological zone, and other villagers should be relocated into 16 concentrated residential areas in a planned city and construction land. At present, the resettlement program has invested 6.4 billion RMB. On October 29, the Ningbo City Government put out a statement that the PX project was forbidden, and the refinery project was stopped. At this point, the situation was pacified, and the total investment losses caused by the Ningbo PX incident amounted to more than 6 billion RMB.

According to the case of Ningbo PX incident, we can obtain the exterior payoff parameters. The total investment estimation of the PX project can be taken as the total social value $V = 55.873$ billion RMB; the investment losses of government officials faced with the continuous resistance movement is $(1\text{-}a)V\text{-}C_2 = 6$ billion RMB; the continuous resistance days from the 22th to 29th is $T = 8$. The initial number of resisters in the opposition group is $N_{j0} = 200$. Considering that local officials have to face the pressure of safeguarding stability, the opposition group J has had more patience than the government official I, $\delta_2 = 0.9$, and $\delta_1 = 0.95$. Because the bargaining power of opposition group a is the key factor determining the final outcome of the protest action, the bargaining power a and the relevant sharing proportion aV of the opposition group are taken as control variables, $a \in [0, 1]$.

B. SIMULATION ANALYSIS OF EVOLUTIONARY RESULTS IN CHINESE NINGBO PX INCIDENT

Under the simulation platform of NetLogo [73], the evolutionary dynamics of the mandatory evacuation of protesters are simulated. The initial number of resisters of the opposition group is set as 200. The bargaining power a can be changed by the slider from 0 to 1. The initial energy value of each agent, named ''Turtle'', is set as 10, and the reproduction threshold of every generation is set as 20. The concrete simulation procedure can be seen in the Appendix.

1) EVOLUTIONARY DYNAMICS ANALYSIS BASED ON SUBGAME MONOTONICITY

According to the replicator dynamic function based on subgame monotonicity (2) and (3), we suppose all of strategies are evenly distributed in the initial state. In other words, the initial numbers of four action types, including resister, acceptance, compromise and evacuation, are set as two hundred. Thus, the initial proportion of protesters taking the Accept strategy is $q_0 = 0.5$. Similarly, the initial proportion of government officials taking the Compromise strategy is $p_0 = 0.5$ as well. Given the payoff parameters and bargaining power a, the Wright manifold is $q^* = \frac{C_2}{aV - c_2 + C_2}$.

Fig. 8 describes the evolutionary dynamic results under various bargaining powers based on subgame monotonicity when the initial proportion of accepting protesters is lower than the Wright manifold, $0 < q_0 < q^*$. In the left picture of Fig. 8, the frequency p_1, which is the proportion of local officials accepting the Compromise strategy, is strictly increasing until it reaches $p_1 = 1$. Moreover, as the bargaining power of protesters enhances, the frequency p_1 is escalating faster and faster. In the right picture of Fig. 8, the frequency q_1, which is the proportion of protesters taking the Accept strategy, should not exceed the critical Wright manifold q^*. Along with the higher bargaining power, the frequency q_1 should be reduced, that is, protesters are more inclined to resist, but not accept.

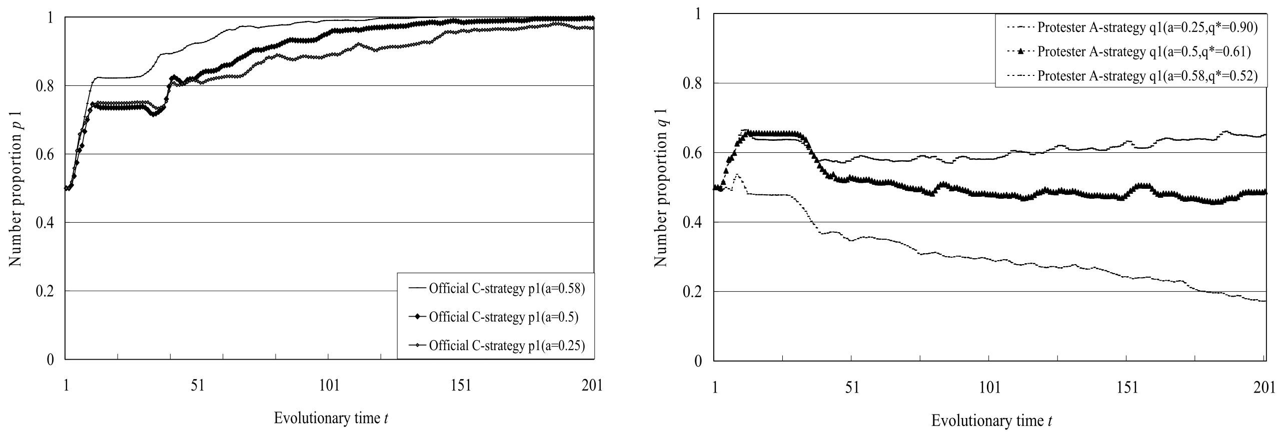


FIGURE 8. Evolutionary dynamic simulation under various bargaining powers based on subgame monotonicity ($q_0 = p_0 = 0.5$).

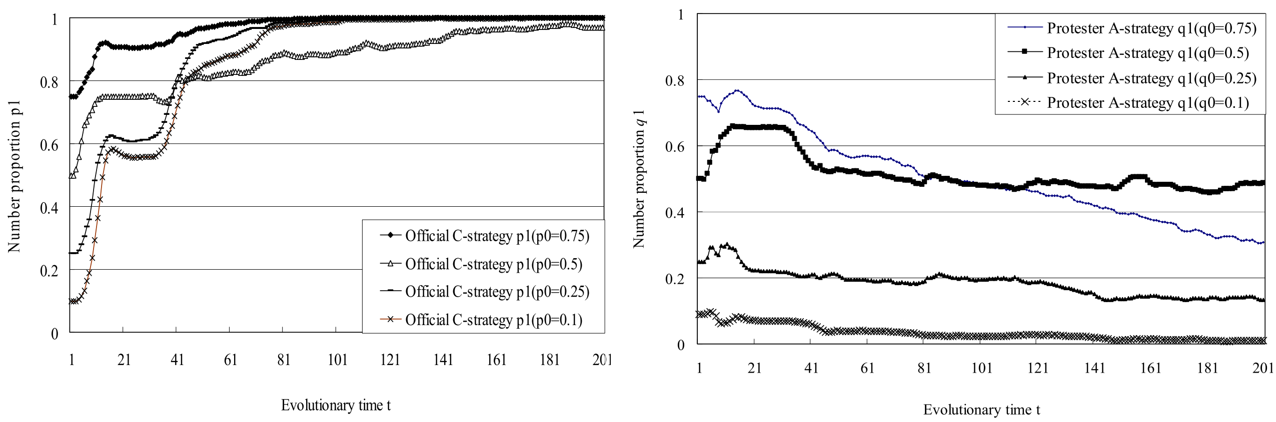


FIGURE 9. Evolutionary dynamic simulation under various initial proportions based on subgame monotonicity ($a = 0.25$).

The final equilibrium state of protesters locates in the region of $(0, q^*)$.

Given the bargaining power $a = 0.25$, the Wright manifold is $q^* = 0.896$. Fig. 9 presents the evolutionary dynamic results under various initial proportions. In the left picture of Fig. 9, the initial numbers of both acceptance and resistance positions among members of the opposition group are set as the same 200 [74], [75]. With the initial proportion falling, the increasing speed of the proportion of local officials taking the Compromise strategy p_1 becomes slower. In the right picture of Fig. 9, the initial numbers of both compromise and evacuation among government officials are set as the same 200. The final equilibrium state of the proportion of protesters taking the Accept strategy q_1, which localizes in the region $(0, q^*)$, is near the initial numbers.

The simulation results of the evolutionary dynamic process in the extensive form game in Fig. 8 and 9 proved the theoretical result based on subgame monotonicity and the Wright manifold. One of the equilibrium states is that all of the government officials take the Compromise strategy, and protesters take the Accept strategy with the proportion of $q \in [0, q^*]$.

2) EVOLUTIONARY DYNAMICS ANALYSIS BASED ON MENTAL MODEL

According to the replicator dynamic function based on mental models (5) and (6), the growth rates of both the officials' Compromise strategy and the protesters' Accept strategy decline to zero under the given mental models. Along with the idea of mental models, Fig. 10 describes the evolutionary dynamics under the various bargaining powers of the protesters. In the left picture of Fig. 10, the initial numbers of those who accept the compromise and evacuation strategies offered by officials are set as the same at 50. According to the officials' E-mental model, the initial proportion of those taking the Accept strategy is set as $q_0 = 1$. We can find that the changes in bargaining power have little influence on the proportion of the Compromise strategy taken by government officials. In the right picture of Fig. 10, the initial numbers of the acceptance and resistance strategies taken by protesters are set as the same at 50. According to the protesters' *P*-mental model, the initial proportion of the Compromise strategy is set as $p_0 = 1$. With the larger bargaining power, the proportion of the Accept strategy taken by the protesters decreases more quickly.

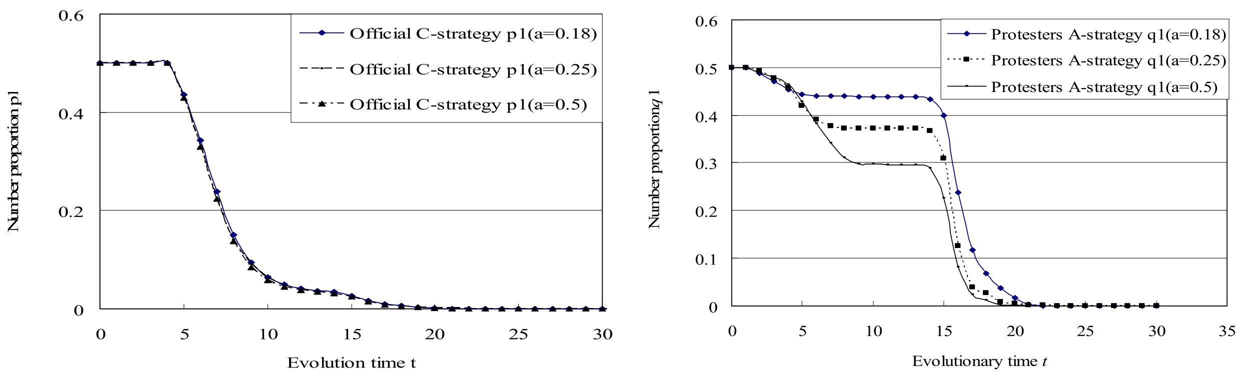


FIGURE 10. Evolutionary dynamic simulation under various bargaining powers based on mental model ($q_0 = p_0 = 0.5$).

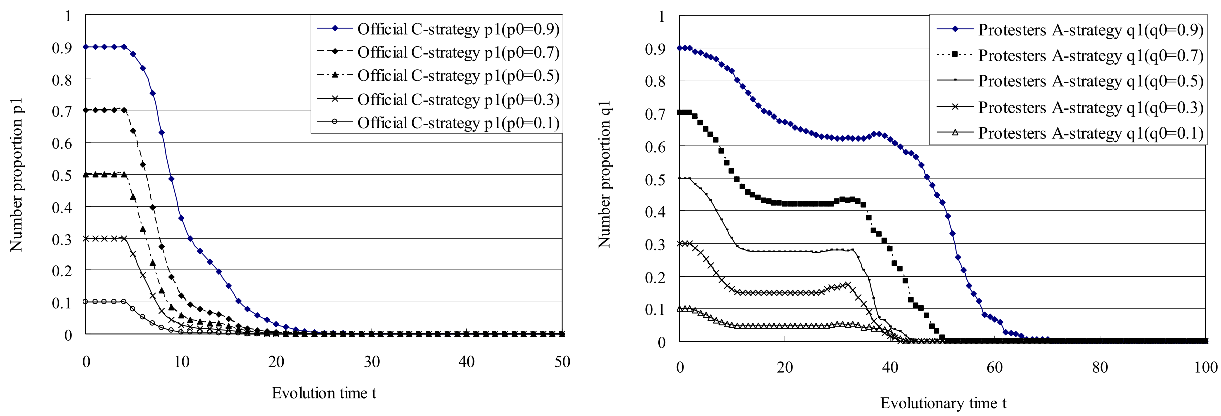


FIGURE 11. Evolutionary dynamic simulation under various initial proportions based on mental model ($a = 0.18$).

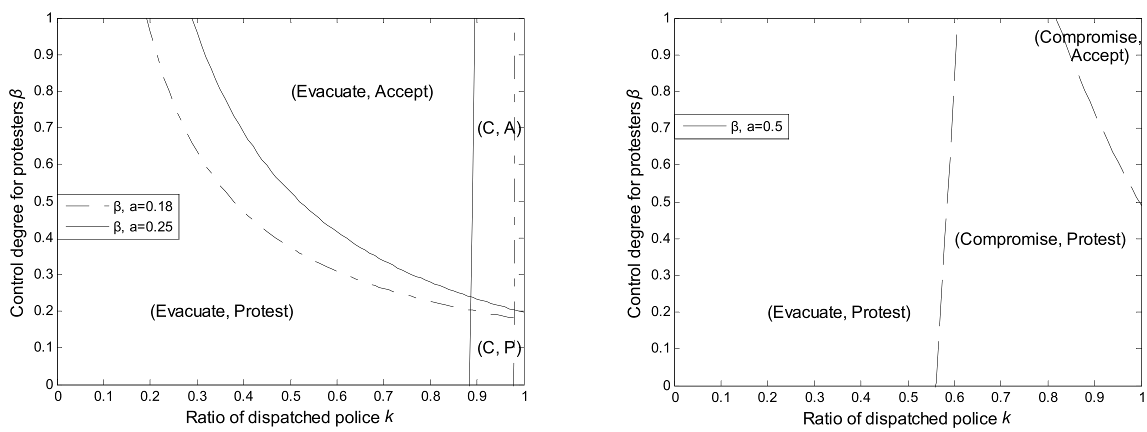


FIGURE 12. Numerical analysis of equilibrium evolution in the case of Chinese Ningbo PX incident.

Given the bargaining power $a = 0.18$, Fig. 11 describes the evolutionary dynamic results under various initial proportions based on the two parties mental models. In the left picture of Fig. 11, the proportion of local officials taking the Compromise strategy p_1 is strictly decreasing until it reaches $p_1 = 0$, which means that the strategy of local officials' convergences to the E-mental model of the Evacuation strategy. When the initial proportion p_0 is lower, frequency p_1 falls increasingly faster. In the right picture of Fig. 11, the proportion of protesters taking the Accept strategy q_1 also decreases until it reaches $q_1 = 0$, which means that the strategy of protesters convergences to the P-mental model of the Resist strategy. When the initial proportion q_0 is lower, frequency q_1 decreases increasingly faster.

The simulation result of Fig. 10 and 11 shows that from the perspective of mental models, the mandatory evacuation problem modeled as evolutionary dynamics in an extensive form game has two deterministic equilibriums: one is {Compromise, Resist}, and the other is {Evacuation, Accept}. Clearly, the idea of mental model not only considers the late-mover's belief learning in the interior of the dynamic stage game but also avoids equilibrium indeterminacy based on subgame monotonicity (That can be seen in the right pictures of Fig. 8 and 9).

Given the above two deterministic equilibriums {Compromise, Resist} and {Evacuation, Accept}, under the corresponding mental models, the numerical analysis of equilibrium evolution in the case of the Chinese Ningbo PX incident can be seen in Fig. 12. We find that as the bargaining power of protesters becomes larger from $a = 0.18$ to 0.25 and 0.5, the effective region of the police successful mandatory evacuation for the protesters, which is {Evacuate, Accept}, diminishes in the left picture of Fig. 12, until it disappears in right picture of Fig. 12. However, the protest action of the opposition group is more likely to be successful when its bargaining power becomes larger.

VI. CONCLUSION

There have been more radical mass demonstrations since the global financial crisis of 2008. These demonstrations represent an important social safety problem, and government officials need to respond quickly and effectively in these emergency situations to evacuate/compel the protesters. Considering the high uncertainties and the confrontational relationship between the police and protesters, there are pronounced distinctions between the problem of a police mandatory evacuation of protesters and the evacuation and pedestrian dynamics of various disaster situations in such locations as buildings, street areas, and subways. In the latter case, there are important questions related to such factors as emergency exits and the structural design of buildings, the safest escape routes, and the crowd panic psychology and behavior. However, in the case of a police mandatory evacuation of protesters, the following issues need to be focused on: the cognitive differences between the conflicting parties, the cost-benefit considerations between the alternative strategies of mandatory evacuation and compromise, the minimal police deployment, and the optimal on-the-spot degree of control (emergency plans).

In this paper, a new analytical approach—mental model—is introduced to analyze the evolutionary dynamics in an extensive form stage game. Next, the evolutionary dynamics of the police mandatory evacuation for the protesters is modeled and analyzed based on mental models. Considering the cognitive differences between the conflicting parties, we build mental models of the interaction between government officials and protesters and subsequently perform the evolutionary dynamic analysis of the mandatory evacuation of protesters. To verify the effectiveness of the model set out, a multiagent simulation analysis based on a real case study of the Ningbo PX incident is presented.

We obtain the following conclusions that include an analytical approach for evolutionary dynamics in an extensive form stage game and practical emergency management insights regarding the police mandatory evacuation for protesters. First, as a new analytical approach for evolutionary dynamics in an extensive form stage game, mental models not only effectively avoid the uncertainty of evolutionary equilibrium but also consider the belief learning in the interior of a dynamic stage game. Second, the practical condition of a police evacuation of protesters mainly includes the cost-benefit weighing between mandatory evacuation and compromise, the number of police required and the police on-the-spot deployment plans. Third, when dealing with protesters marching along a street, it will be more effective if the police implement evacuation measures aiming at the first few rows of protesters. However, in the case of a protest rally gathering at iconic buildings (or around several demonstration leaders), the emergency plan of a mandatory evacuation of the protesters will have inferior outcomes.

Notably, any demonstration or street protest is the action by a mass group or a collection of groups of people demanding a political action or for some other reason, which is one of the fundamental rights of any citizen. However, for terrorist and crime attacks, governments should take a firm stance and implement an iron-hand policy because these events go against basic human values, and there can thus be no compromise. In this paper, we develop a structural game theoretical framework for the police mandatory evacuation of protesters. In our future research, we shall specifically analyze the functional relationship of costs and benefits in the best response model. Because it is very difficult and expensive to obtain related data regarding such social crises, computer simulation models can be used to discover new insights into our understanding of human behavior of protesters and performance in mandatory evacuation situations. In this paper, we do not make a more detailed distinction between the protesters. Protesters with different characteristics may exhibit different behaviors. In future research, protesters can be divided into different types, such as active/passive, armed/unarmed, and young/old. At the same time, we have noted a new trend in recent years, that is, the youth-led political protests in many countries and regions are on the rise. Such protests are often characterized by irrational or even violent acts of terror, last for longer time, and they may take a very different approach than that of their predecessors. How to deal with such protests is a serious challenge for the governments involved. In view of the youth-led political protests, developing an extensive evolutionary mental game model for the police mandatory evacuation of protesters will be an extended research direction of this paper in the future. Furthermore, perhaps the authors should classify the protesters in more detail (e.g., active, inactive, armed, or unarmed) and consider options for their location in the crowd.

APPENDIX: NETLOGO SIMULATION PROCEDURE OF SUBGAME MONOTONICITY

```
globals [cycles c1 c2 c11 c22 q11 q12 q21 q22 q0 p11 p12 p21 p22]
breed [ p1 ]
breed [ p2 ]
breed [ q1 ]
breed [ q2 ]
turtles-own [turtle-energy xhere yhere trys]
patches-own [energy energy-time]
to setup
ca
set cycles 0
set c22 60 + (1 - a) * v
set c2 c22 * (1 - b2) / (1 - b2 * b2 * b2 * b2 * b2 * b2 * b2 * b2)
set c1 c2
set c11 (1 - b1 * b1 * b1 * b1 * b1 * b1 * b1 * b1) * c1 / (1 - b1)
set q11 a * V - c1
set q12 a * v - c1
set q21 ( - c1)
set q22 a * V - c11
set q0 c22 / (a * v - c2 + c22)
set p11 (1 - a) * V
set p12 (1 - a) * V
set p21 V - c2
set p22 (1 - a) * V - c22
ask patches [set pcolor green]
create-p1 init-p1
create-p2 init-p2
create-q1 init-q1
create-q2 init-q2
ask p1
[set color black]
ask p2
[set color blue]
ask q1
[set color red]
ask q2
[set color yellow]
ask turtles
[
setxy random world-width random world-height
set turtle-energy init-energy
]
do-plot
end
to go
ask patches with [energy-time > = energy-time-threshold and pcolor = green + 3]
[set pcolor green]
ask turtles
[
move ; turtles move forward with a random change to heading of + or - 45 degrees
] ; there is a cost to moving
get-energy ; turtles acquire energy from the patch that they are on, if possible
ask turtles
[
reproduce
perish
]
if not any? turtles
[
do-plot-zero
stop
]
do-plot
set cycles cycles + 1
ask patches [set energy-time energy-time + 1]
end
to move
set xhere xcor
set yhere ycor
set trys 1
while [xhere = xcor and yhere = ycor and trys < 9]
[rt random 46 - random 46
if count turtles-at dx dy < 2
[fd 1]
set trys trys + 1]
set turtle-energy turtle-energy - 0.5
end
to get-energy
; This procedure allocates energy to turtles, depending on whether there is one or two turtles.
; If there are two, then the payoff depends on each turtle's type.
ask patches with [count turtles-here = 1 and energy-time > = energy-time-threshold]
[
ask turtles-here [set turtle-energy turtle-energy + 1]
set energy-time 0
set pcolor green + 1
]
ask patches with [count turtles-here = 2 and energy-time > = energy-time-threshold]
[
without-interruption
[
ask one-of turtles-here
[
if breed = p1
[
ask other turtles-here
[
if breed = q1
[
set turtle-energy (turtle-energy + (a * v - c1) )
ask myself [ set turtle-energy ([turtle-energy] of myself + (1 - a) * v)]
```

```
if breed = q2
[
set turtle-energy (turtle-energy + (a * v - c1))
ask myself [ set turtle-energy ([turtle-energy] of myself +
(1 - a) * v) ]
]
]
]
]
if breed = p2
[
ask other turtles-here
[
if breed = q1
[
set turtle-energy (turtle-energy - c1 )
ask myself [ set turtle-energy ([turtle-energy] of myself +
v - c2)]
if breed = q2
[
set turtle-energy (turtle-energy + a * v - c11)
ask myself [ set turtle-energy ([turtle-energy] of myself +
(1 - a) * v - c22) ]
]
]
]
]
if breed = q1
[
ask other turtles-here
[
if breed = p1
[
set turtle-energy (turtle-energy + (1 - a) * v)
ask myself [ set turtle-energy ([turtle-energy] of myself +
a * v - c1)]
if breed = p2
[
set turtle-energy (turtle-energy + v - c2)
ask myself [ set turtle-energy ([turtle-energy] of myself -
c1) ]
]
]
]
]
if breed = q2
[
ask other turtles-here
[
if breed = p1
[
set turtle-energy (turtle-energy + (1 - a) * v)
ask myself [ set turtle-energy ([turtle-energy] of myself +
a * v - c1)]
if breed = p2
[
set turtle-energy (turtle-energy + (1 - a) * v - c22)
ask myself [ set turtle-energy ([turtle-energy] of myself +
a * v - c11) ]
]
]
]
]
]
set energy-time 0
set pcolor green + 3
]
]
end
to reproduce
if turtle-energy > reproduce-threshold
[
set turtle-energy turtle-energy / 2
hatch 1 [rt random 360 move]
]
end
to perish
if turtle-energy < 0 [die]
end
to do-plot
set-current-plot "Proportions"
set-current-plot-pen "p1"
show count p1
show count p2
plot count p1 / ( count p1 + count p2)
set-current-plot-pen "q1"
show count q1
show count q2
plot count q1 / ( count q1 + count q2 )
set-current-plot-pen "p2"
show count p1
show count p2
plot count p2 / ( count p1 + count p2)
end
to do-plot-zero
set-current-plot "Proportions"
set-current-plot-pen "p1"
plot 0
set-current-plot-pen "q1"
plot 0
set-current-plot-pen "p2"
plot 0
end
```

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