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Research Article

Risk-Averse Evolutionary Game Model of Aviation Joint Emergency Response

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We study effects of risk-averse attitude of both participators in aviation joint emergency response on the coevolution of cooperation mechanisms and individual preferences between airport and nonprofit organization. First, based on the current aviation joint emergency mechanism in China, we put forward two mechanisms to select the joint nonprofit organization, including reputation cooperation and bidding competition. Meanwhile, we consider two preferences including altruism and selfishness. Then we build replicator dynamics equations using the theory of conditional value-at-risk (CVaR) taking risk aversion attitude into account. Finally, we introduce the factor of government and give all participators some suggestions. We show that the risk-averse attitude of the other game participator affects the one participator's decision and the effects subject to some parameters.

1. Introduction

Emergencies happen suddenly, and they are likely to cause significant casualties, property losses, and other serious social problems [1]. Airports always have a higher disaster probability than other accidental locations. Recently, aviation joint emergency response mechanisms have been studied and reach some academic achievements [2, 3]. Generally, airports are profit organizations to maximize their expected return in emergencies, including increasing reputation and decreasing compensation to victims. Hospitals and firefighters are nonprofit organizations to realize their responsibility and social value by saving life and property. Governments are the third departments to stabilize the society by supporting and supervising relief organizations. Now, Chinese aviation joint emergency mechanisms are mainly guided by airports. Airports buy the service from nonprofit organizations, schedule the emergency plans, and coordinate with nonprofit organizations.

In aviation joint emergency mechanisms, Zhu and Luo [2] put forward the solutions that the joint emergency response system to aviation calamities should work under command of emergency headquarters of aviation authorities at all levels, employ virtual network organization, and put participators' responsibilities in order, making sense in quick response and coordination. Disaster response center in the north of Salt Lake City, Utah, USA, has handled several air crashes successfully coordinating with polices, firefighters, and other relief organizations [3]. De-Sheng and Wei-An [4] build a random matching game model to analyze the influence of contracting cost on the interaction between formal contracts and informal contracts. Abbasi [5] studies the mechanisms of emergency response network evolution by examining the link formation pattern among participators involved in a real emergency collaboration network.

In cooperation, some researches focus on the evolution of cooperation among altruistic preference and selfish individuals [6]. Nowak et al. study evolutionary game dynamics and specify the conditions required for natural selection to favor the emergence of cooperation and define evolutionary stability in finite populations [7]. Faraj and Xiao investigate the coordination practices of a medical trauma center and develop a coordination-practice perspective that emphasizes expertise coordination and dialogic coordination

[8]. Kapucu analyzes the cooperation among public and nonprofit organizations to achieve public service goals in emergencies and examines the factors that contribute to successful public-nonprofit partnerships [9]. Gürerk et al. provide new empirical insights into Tiebout's intuition by showing that self-selection in open heterogeneous communities can significantly foster communities' success [10].

Perc and Szolnoki reviewed recent works on evolutionary games incorporating coevolutionary rules and describe many factors in evolutionary process. This mini review on coevolutionary games gives us a clear line about research on evolutionary games incorporating coevolutionary rules [11]. Szabó and Szolnoki studied spatial evolutionary games as a personal character is tuned from selfishness to other regarding preferences via fraternity. The paper gives a utility function of its income and others' payoff with a weight factor [12]. Buesser et al. presented a systematic numerical investigation of standard evolutionary games on weighted networks, which extends previous work on unweighted networks, and they found that taking the weights into account only changes the results slightly with respect to the unweighted network [13]. Carlsen et al. studied future robot systems for civil protection based on a coevolutionary scenario approach and the development of different evolutionary paths, and they considered opportunities, threats, and ethical aspects in the domestic security and safety sector and discussed the above aspects in the context of different scenarios of different future societies [14].

In the applications of game theory in emergency management, Dehai and Lijuan put forward two city demolition modes and analyze the emergencies of equilibrium evolution learned by Akihiko's model about evolutionary analysis of game equilibrium with interaction between different cultures [15]. Feng and Wu use game theory model to find the retailers' optimal order quantity by the conditional value-at-risk as a risk measure and considering emergencies leads to the decision makers risk aversion [1]. Li et al. investigate the evolution of cooperation on supply networks focusing on the impacts of network topologies in emergency management and offer a useful insight into understanding complex strategy behaviors in supply networks [16]. Abbasi et al. show actors' interconnectedness in an emergency response operation [17].

Since 2002, CVaR is introduced by Roekafller and Uryasev [18, 19] and used widely from risky assets to any risky decisions, including logistics [20–22] and disasters [23–25]. Chen et al. studied the collective-risk social dilemma with risky assets in well-mixed and structured populations. They found that in low-risk situations bounded rational allocation of assets works the best, while in high-risk situations the simplest uniform distribution of assets among all the groups is optimal, which indicate that prosocial behavior depends sensitively on the potential losses [26]. Chen et al. studied "problems of the commons" with group performance dependent risk levels, and they showed that stronger feedback between group performance and risk level is in general more favorable for the successful evolution of public cooperation [27]. Xia et al. studied dynamic instability of cooperation due to diverse activity patterns in evolutionary social dilemmas, and they showed that if the interaction network is not strongly heterogeneous, the overall failure of cooperation evolution is not impaired, which may be because inactivity negatively affects the potency of low-degree defectors [28]. From above, we can see that there are many researches which have been done in terms of risk aversion in evolutionary games. However, in those works with risk aversion in evolutionary games, there are few studies using the tool of CVaR to express the evolutionary process. At present, there are many papers on relationship of governments and nonprofit organizations [29–32]. But few papers are about the relationship between airports and nonprofit organizations in emergency management and evolutionary game in emergency management taking participators' risk preferences into account. Therefore, this paper is to study the coevolution of cooperation mechanisms and risk preferences among airports and nonprofit organizations. It is not difficult to imagine that players, including airport and nonprofit organizations, are risk-averse under emergency situations. Inspired by the conditional value-at-risk (CVaR) [20–22], we use CVaR instead of expected return and construct replicator dynamics equations.

The rest of this paper is organized as follows: Section 2 presents evolutionary game between airport and nonprofit organization for analyzing the replicator dynamics equations with risk-averse attitude. Section 3 shows the effect of government on the evolutionary equilibrium and gives some suggestions for actors. Section 4 concludes a brief discussion of theoretical and practical implications. At last, it presents the future researches.

2. Evolutionary Game of Aviation Joint Emergency Mechanisms

2.1. The Null Hypothesis. As we all know, there are some nonprofit organizations, such as hospitals, that operate for both nonprofit and profit purpose, and more and more international governments buy service from nonprofit organizations by bidding. In China, many airports cooperate with nonprofit organizations directly who have bigger size and higher reputation, increasing airports' reputation and cognitive safety for travelers. Hence, the assumption that airport selects the joint organizations by either reputation cooperation mechanism or bidding competition mechanism is reasonable and practical. Some nonprofit organizations pursue loyalty and social value. They are altruistic. On the other hand, some organizations prefer power and position. They are selfish individuals. Altruism always takes actions for high degree of coordination and obeys the airports' commands. However, selfish individuals always make decisions without authorization for saving life and property. So the assumption that nonprofit organization has two preferences is reasonable and practical.

In order to simplify the analysis, we have some hypotheses as follows. (1) Airports take two joint mechanisms that are reputation cooperation and bidding competition. Reputation cooperation mechanism prefers sharing value and codetermination. Bidding competition mechanism prefers leadership and command. (2) Nonprofit organization has two preferences that are altruism and selfishness. Altruism prefers loyalty and social value. Selfishness prefers power and important position. (3) Altruism always has a sense of disloyalty under bidding competition mechanism, which makes altruism produce subjective cost. Selfish individuals always gain more extra payoff from mechanism of reputation cooperation. (4) Airport must take cost to supervise and manage joint organizations to support the bidding competition mechanism. Cost for selfishness is larger than altruism. (5) Demand of an accident about coordination is a constant d. It will affect airport payoff directly. (6) The risk-averse degree of airport is η_1 and the risk-averse degree of nonprofit organization is η_2. The random payoff deals with 0-1 variable. x, y represent the random selection variable of airport and nonprofit organization, respectively.

2.2. Evolutionary Game between Airport and Nonprofit Organization. We use the following notations throughout this paper:

H: the same payoff for both airport and nonprofit organization when nonprofit organization prefers altruism,

L: the same payoff for both airport and nonprofit organization when nonprofit organization prefers selfishness,

d: the constant demand of an accident for degree of coordination,

λ: the speculative extra payoff of nonprofit organization when airport adopts reputation cooperation mechanism,

λ_1: airport's management cost for altruism,

λ_2: airport's management cost for selfishness,

C: altruism's subjective cost for disloyalty.

$\lambda_1 \le \lambda_2 \le \lambda$, $H \le L + \lambda$, $H - C \ge L$, and $\lambda \le \lambda_2 + (1/M)\lambda_1$, noting that the speculative extra payoff λ would not be much too bigger, and M is a quite big number. Coevolution of cooperation mechanisms and preferences are presented in Table 1.

2.3. Analysis of the Evolutionary Process with Risk-Averse. We note that the probability of adopting reputation cooperation mechanism is p. Accordingly, the probability of adopting bidding competition mechanism is $1 - p$. We note that the portion of altruism is q and the portion of selfishness is $1 - q$. Taking advantage of the tool of risk management in financial, conditional value-at-risk (CVaR) [20–22], we consider the risk attitudes of actors. The analysis is as follows.

(1) Analysis of Evolutionary Process for Airport. The CVaR of reputation cooperation mechanism is represented by

$$\begin{aligned}
\mathrm{CVaR}_{11} &= \max\left\{r_{11} - \frac{1}{1-\eta_1}E\left(r_{11} - \pi_{11}(y)\right)^+\right\},\\
F_{11} &= r_{11} - \frac{1}{1-\eta_1}E\left(r_{11} - \pi_{11}(y)\right)^+\\
&= r_{11} - \frac{q}{1-\eta_1}\left(r_{11} - H + d\right)^+\\
&\quad - \frac{1-q}{1-\eta_1}\left(r_{11} - L + d + \lambda\right)^+,\\
\mathrm{CVaR}_{11} &= L - d - \lambda \quad \text{when } q \le \eta_1,\\
\mathrm{CVaR}_{11} &= H - d - \frac{1-q}{1-\eta_1}\left(H - L + \lambda\right) \quad \text{when } q > \eta_1.
\end{aligned} \tag{1}$$

The CVaR of bidding competition mechanism is represented by

$$\begin{aligned}
\mathrm{CVaR}_{12} &= \max\left\{r_{12} - \frac{1}{1-\eta_1}E\left(r_{12} - \pi_{12}(y)\right)^+\right\},\\
F_{12} &= r_{12} - \frac{q}{1-\eta_1}\left(r_{12} - H + d + \lambda_1\right)^+\\
&\quad - \frac{1-q}{1-\eta_1}\left(r_{12} - L + d + \lambda_2\right)^+,\\
\mathrm{CVaR}_{12} &= L - d - \lambda_2 \quad \text{when } q \le \eta_1,\\
\mathrm{CVaR}_{12} &= H - d - \lambda_1 - \frac{1-q}{1-\eta_1}\left(H - L - \lambda_1 + \lambda_2\right)\\
&\qquad \text{when } q > \eta_1.
\end{aligned} \tag{2}$$

The CVaR of reputation cooperation and bidding competition mechanism is represented by

$$\begin{aligned}
\mathrm{CVaR}_1 &= \max\left\{r_1 - \frac{1}{1-\eta_1}E\left(r_1 - \pi_1(x, y)\right)^+\right\},\\
F_1 &= r_1 - \frac{p}{1-\eta_1}\left(r_1 - \mathrm{CVaR}_{11}\right)^+\\
&\quad - \frac{1-p}{1-\eta_1}\left(r_1 - \mathrm{CVaR}_{12}\right)^+,\\
\mathrm{CVaR}_1 &= L - d - \lambda_2 - \frac{p}{1-\eta_1}\left(\lambda - \lambda_2\right)\\
&\qquad \text{when } q \le \eta_1,\ p \le 1 - \eta_1,\\
\mathrm{CVaR}_1 &= L - d - \lambda \quad \text{when } q \le \eta_1,\ p > 1 - \eta_1,\\
\mathrm{CVaR}_1 &= H - d - \lambda_1 - \frac{1-q}{1-\eta_1}\left(H - L - \lambda_1 + \lambda_2\right)\\
&\qquad \text{when } q > \eta_1,\ p \le \eta_1,\\
\mathrm{CVaR}_1 &= \frac{q-\eta_1}{1-\eta_1}\lambda_1 - \frac{1-q}{1-\eta_1}\left(\lambda - \lambda_2\right)\\
&\qquad \text{when } q > \eta_1,\ p > \eta_1.
\end{aligned} \tag{3}$$

The replicator dynamics equation of reputation cooperation mechanism for airport is represented by

$$G(p) = \frac{dp}{dt} = p * \left(\mathrm{CVaR}_{11} - \mathrm{CVaR}_1\right). \tag{4}$$

Table 1: Coevolution of cooperation mechanisms and preferences.

(Airport, nonprofit organization)	Altruistic preference (q)	Selfish preference ($1-q$)
Reputation cooperation (p)	$(H-d, H)$	$(L-d-\lambda, L+\lambda)$
Bidding competition ($1-p$)	$(H-d-\lambda_1, H-C)$	$(L-d-\lambda_2, L)$

$G(p) = dp/dt = 0$ means that the evolutionary game reaches a stable state.

When $q \le \eta_1$ and $p \le 1-\eta_1$, $p^* = 0$, $p^* = 1-\eta_1$. We have $G(p) < 0$, $G'(0) > 0$, $G'(1-\eta_1) < 0$; then $p^* = 1-\eta_1$ is the evolutionary stable strategy (ESS).

When $q \le \eta_1$ and $p > 1-\eta_1$, $G(p) = 0$, $G'(p) = 0$.

When $q > \eta_1$ and $p \le \eta_1$, $p^* = 0$, $q^* = (\lambda+\eta_1\lambda_1-\lambda_2)/(\lambda+\lambda_1-\lambda_2) > \eta_1$. If $q \le q^*$, then $G(p) < 0$, $G'(0) < 0$, and $p^* = 0$ is the ESS. If $q > q^*$, then $G(p) > 0$, $G'(0) > 0$, and $p^* = 0$ is not the ESS.

When $q > \eta_1$ and $p > \eta_1$, $p^* = 1$, $q^* = (\lambda+\eta_1\lambda_1-\lambda_2)/(\lambda+\lambda_1-\lambda_2) > \eta_1$. If $q \le q^*$, then $G(p) < 0$, $G'(1) > 0$, and $p^* = 1$ is not the ESS. If $q > q^*$, then $G(p) > 0$, $G'(1) < 0$, and $p^* = 1$ is the ESS.

(2) Analysis of Evolutionary Process for Nonprofit Organization. The CVaR of altruism is represented by

$$\begin{aligned}
\mathrm{CVaR}_{21} &= \max\left\{r_{21} - \frac{1}{1-\eta_2}E\left(r_{21} - \pi_{21}(x)\right)^+\right\},\\
F_{21} &= r_{21} - \frac{p}{1-\eta_2}\left(r_{21} - H\right)^+ \\
&\quad - \frac{1-p}{1-\eta_2}\left(r_{21} - H + C\right)^+,\\
\mathrm{CVaR}_{21} &= H - C \quad \text{when } p \le \eta_2,\\
\mathrm{CVaR}_{21} &= H - \frac{1-p}{1-\eta_2}C \quad \text{when } p > \eta_2.
\end{aligned} \tag{5}$$

The CVaR of selfishness is represented by

$$\begin{aligned}
\mathrm{CVaR}_{22} &= L \quad \text{when } p \le \eta_2,\\
\mathrm{CVaR}_{22} &= L + \frac{p-\eta_2}{1-\eta_2}\lambda \quad \text{when } p > \eta_2.
\end{aligned} \tag{6}$$

The CVaR of altruism and selfishness is represented by

$$\begin{aligned}
\mathrm{CVaR}_2 &= \max\left\{r_2 - \frac{1}{1-\eta_2}E\left(r_2 - \pi_2(x,y)\right)^+\right\},\\
\mathrm{CVaR}_2 &= L \quad \text{when } p \le \eta_2,\ q \le \eta_2,\\
\mathrm{CVaR}_2 &= \frac{q-\eta_2}{1-\eta_2}(H-C) + \frac{1-q}{1-\eta_2}L \\
&\qquad \text{when } p \le \eta_2,\ q > \eta_2,\\
\mathrm{CVaR}_2 &= \frac{q-\eta_2}{1-\eta_2}\left(L + \frac{p-\eta_2}{1-\eta_2}\lambda\right) \\
&\quad - \frac{1-q}{1-\eta_2}\left(H - \frac{1-p}{1-\eta_2}C\right) \\
&\qquad \text{when } p > \eta_2,\ q \le 1-\eta_2,\\
\mathrm{CVaR}_2 &= H - \frac{1-p}{1-\eta_2}C \quad \text{when } p > \eta_2,\ q > 1-\eta_2.
\end{aligned} \tag{7}$$

The replicator dynamics equation of altruism preference for nonprofit organization is represented by

$$G(q) = \frac{dq}{dt} = q * \left(\mathrm{CVaR}_{21} - \mathrm{CVaR}_2\right). \tag{8}$$

When $p \le \eta_2$ and $q \le \eta_2$, $q^* = 0$. We have $G(q) > 0$, $G'(0) > 0$; then $q^* = 0$ is not the ESS.

When $p \le \eta_2$ and $q > \eta_2$, $q^* = 1$, $G(q) > 0$, and $G'(1) < 0$; then $q^* = 1$ is the ESS.

When $p > \eta_2$ and $q \le 1-\eta_2$, $q^* = 0$, $q^* = 1-\eta_2$, and $p^* = 1 - ((L+\lambda-H)/(\lambda-C))(1-\eta_2) > \eta_2$. If $p \le p^*$, then $G(q) > 0$, $G'(0) > 0$, and $q^* = 0$ is not the ESS. If $p > p^*$, then $G(p) < 0$, $G'(1-\eta_2) < 0$, and $q^* = 1-\eta_2$ is the ESS.

When $p > \eta_2$ and $q > 1-\eta_2$, $G(q) = 0$, $G'(q) = 0$.

(3) The Stability of Evolutionary Game as a Whole. When $\eta_1 < 1 - ((\lambda+\lambda_1-\lambda_2)/\lambda_1)\eta_2 < 1-\eta_2$ and $\eta_2 < \lambda_1/(\lambda+\lambda_1-\lambda_2)$, ESS is $p^* = 1-((L+\lambda-H)/(\lambda-C))(1-\eta_2)$, $q^* = (\lambda+\eta_1\lambda_1-\lambda_2)/(\lambda+\lambda_1-\lambda_2)$.

With the exception of above situations, there does not exist an ESS as a whole. Actor prejudges the opponent's strategy using its experience and makes the optimum reaction. This learning and evolution process will be dynamic and would not reach a stable state, so the ESS would not exist for the wrong learning paths.

2.4. Results and Discussion. (1) Based on expected theory, the ESS is $\tilde{p}^* = (H-C-L)/(\lambda-C)$, $\tilde{q}^* = (\lambda-\lambda_2)/(\lambda+\lambda_1-\lambda_2)$. When $\eta_1 < 1-((\lambda+\lambda_1-\lambda_2)/\lambda_1)\eta_2 < 1-\eta_2$ and $\eta_2 < \lambda_1/(\lambda+\lambda_1-\lambda_2)$, that is, the risk attitudes of airport and nonprofit organizations are confided by parameters, we have $p^* \ge \tilde{p}^*$ and $q^* \ge \tilde{q}^*$, meaning that the risk attitudes affect the evolutionary game. We can conclude that they may not reach ESS, and if the risk attitudes of airport and emergency organizations meet the constraint conditions, the evolution can reach ESS. If the risk attitude of airport and the risk attitude of emergency organizations are higher simultaneously, the ESS is more likely to be the strategies (reputation cooperation and altruism behavior), but the strategies (reputation cooperation and altruism behavior) could not be reached completely. This can explain why it is reasonable in practice that reputation cooperation can coexist with bidding competition and altruism behaviors can coexist with selfish behaviors.

(2) The evolutionary strategy is affected not only by risk-averse attitude of itself but also by the risk-averse attitude of the game rival. From the expression of ESS, we can see that the airport's selection for reputation cooperation is more likely with the greater risk-averse attitude of emergency organizations and the emergency organizations' selection for altruism behaviors is more likely with the greater risk-averse attitude of airport. The explanations are as follows. (1) The replicator dynamics equation describes the logical relationship of mechanisms and preferences. Meanwhile, the adoptive fitness of mechanism is affected by the proportion distribution of preference and the adoptive fitness of preference is affected by the probability distribution of mechanism. (2) The reputation cooperation mechanism means the airport prefers to share value and codetermination [33]. If emergency organizations have higher risk-averse attitudes, the reputation cooperation mechanism is selected by airport based on the incentive theory to meet emergency organizations' psychological requirement. (3) The evolution of preference is driven by loyalty, social value, responsibility and power, and influence. If the airport has higher risk-averse attitude, the emergency organizations will be more inclined to altruism behavior to realize their intrinsic value and social responsibility. On the other hand, emergency organizations will deem that the airport has more strict supervise with higher risk-averse attitude, and they will prefer altruism behaviors to avoid penalties.

(3) From the whole ESS equation, if the supervised and managerial cost of airport is higher, the ESS is more easy to reach just for the enlarged initial feasible region of risk-averse degree. At the same time, q^* is smaller, which means the proportion of altruism is less. The possible reason is that the altruism prefers loyalty. The higher supervised and managerial cost mean stronger effort in supervising the nonprofit organization. When the speculative extra payoff λ is higher, the ESS is impossibly reach that p^* is smaller and q^* is larger. The possible reason is that the payoff of altruism is higher than selfish individual when airport adopts the bidding competition mechanism. Airport is more likely to adopt the bidding competition mechanism when the speculative extra payoff is higher.

(4) The evolutionary state strategies are affected by parameters of payoff and risk-averse attitude. For airport, it can reveal risk-averse attitude of itself and decrease supervised and managerial cost by increasing professional management to affect other emergency organizations' behaviors. For nonprofit emergency organizations, they can make use of their professional rescue skill and more free behavior mechanism to create more chance to participate in the emergency decisions, which will speed the evolution process of codetermination. However, for government, it can change payoffs of both sides of the evolutionary game to affect the evolutionary process.

2.5. Numerical Analysis. We assume the parameters equal to value as in Table 2.

Table 2: Parameters values.

H	d	L	λ	λ_1	λ_2	C
10	2	8	3	1	3	1

Based on the above theory analysis, we can get the final decisions from both participators with different risk-averse attitudes like Table 3. In Table 3, the first column represents the values of η_1, the first line represents the values of η_2, and the values in middle represent the ESS (p^*, q^*).

From Table 3, we can see that the results of the numerical analysis are consistent with the above results of theory analysis (1), (2), (3), and (4) in Section 2.4. Different from our intuition, the risk-averse attitude of one participator affects the other participator's decision.

3. Evolutionary Game with Governmental Intervention

3.1. Evolutionary Game Model. If we cannot get the equilibrium or $q^* \ll 0.5$, the government should subsidize the altruism for the high coordination degree. Because the reputation cooperation mechanism faces a higher risk for a selfish individual, government should subsidize airports who adopt reputation cooperation mechanism [34–36]. The combination of strategies is presented in Table 4.

When $\lambda - \lambda_2 < S < \lambda_1 < \lambda_2 < \lambda$ and $0 \le S < L + \lambda - H$, if S feasible zone is nonnull, the unique ESS is $p^* = 1 - (1 - \eta_2)(L + \lambda - H - S)/(\lambda - C)$, $q^* = (\lambda + \eta_1 \lambda_1 - \lambda_2 + (1 - \eta_1)S)/(\lambda + \lambda_1 - \lambda_2)$. Otherwise, the evolutionary game would not reach the evolutionary stability.

The improvement of governmental subsidy increases the probability of reputation cooperation mechanism and the proportion of altruistic preference. However, the evolutionary game cannot reach the stable state $p^* = 1, q^* = 1$ unless $\eta_1 = 1, \eta_2 = 1$. This result certainly explains that it is reasonable to adopt both reputation cooperation and bidding competition mechanisms for airports. Meanwhile, it is reasonable for nonprofit organization preferring the combination of altruism and selfishness. The risk attitude and governmental intervention affect the participators' strategy. This can help managers to make decisions.

From the above analysis, we can see that government can change payoffs of both sides of the evolutionary game to affect the evolutionary process. And the decisions of governmental subsidy need to meet some constraint conditions, which require the government to make decisions seriously; otherwise this will lead to negative effectiveness.

3.2. Numerical Analysis. We continue using the values in Section 2.5, and we can get the ESS as Table 5. From Table 5, we can see that when S is larger, p^* is larger and q^* is larger; that is, the airport prefers selecting reputation cooperation mechanism and nonprofit organizations prefer altruism behaviors, which leads to a more efficient and harmonious result.

Table 3: The ESS with different risk-averse attitudes.

(p^*, q^*)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.1	0.55, 0.1	0.6, 0.1	0.65, 0.1	0.7, 0.1	0.75, 0.1	0.8, 0.1	0.85, 0.1	0.9, 0.1	0.95, 0.1
0.2	0.55, 0.2	0.6, 0.2	0.65, 0.2	0.7, 0.2	0.75, 0.2	0.8, 0.2	0.85, 0.2	0.9, 0.2	Null
0.3	0.55, 0.3	0.6, 0.3	0.65, 0.3	0.7, 0.3	0.75, 0.3	0.8, 0.3	0.85, 0.3	Null	Null
0.4	0.55, 0.4	0.6, 0.4	0.65, 0.4	0.7, 0.4	0.75, 0.4	0.8, 0.4	Null	Null	Null
0.5	0.55, 0.5	0.6, 0.5	0.65, 0.5	0.7, 0.5	0.75, 0.5	Null	Null	Null	Null
0.6	0.55, 0.6	0.6, 0.6	0.65, 0.6	0.7, 0.6	Null	Null	Null	Null	Null
0.7	0.55, 0.7	0.6, 0.7	0.65, 0.7	Null	Null	Null	Null	Null	Null
0.8	0.55, 0.8	0.6, 0.8	Null	Null	Null	Null	Null	Null	Null
0.9	0.55, 0.9	Null	Null	Null	Null	Null	Null	Null	Null

Table 4: Coevolution of cooperation mechanisms and preferences with government.

(Airport, nonprofit organization)	Altruistic preference (q)	Selfish preference ($1-q$)
Reputation cooperation (p)	$(H-d+S, H+S)$	$(L-d-\lambda+S, L+\lambda)$
Bidding competition ($1-p$)	$(H-d-\lambda_1, H-C+S)$	$(L-d-\lambda_2, L)$

Table 5: The ESS with different risk-averse attitudes.

(a) When $S = 0.2$

(p^*, q^*)	0.2	0.5	0.8
0.2	0.68, 0.36	0.8, 0.36	0.92, 0.36
0.5	0.68, 0.6	0.8, 0.6	Null
0.8	0.68, 0.84	Null	Null

(b) When $S = 0.5$

(p^*, q^*)	0.2	0.5	0.8
0.2	0.8, 0.6	0.875, 0.6	0.95, 0.6
0.5	0.8, 0.75	0.875, 0.75	Null
0.8	0.8, 0.9	Null	Null

(c) When $S = 0.8$

(p^*, q^*)	0.2	0.5	0.8
0.2	0.92, 0.84	0.95, 0.84	0.98, 0.84
0.5	0.92, 0.9	0.95, 0.9	Null
0.8	0.92, 0.96	Null	Null

3.3. Advises for Actors. Currently, in Chinese aviation joint emergency response, airport emergency management institution generally takes a leader role. It makes emergency plans and arranges work for joint nonprofit organizations. The government supervises and supports the emergency management. Nash equilibrium represents the Pareto state and harmonious coordination represents the better rescue management.

Firstly, the government should evaluate the risk-averse degree for participators. According to the result, it may determine the quantity of subsidy to attain the Pareto state. Meanwhile, in order to quickly obtain the expected evolutionary result, government can make rules. For example, some nonprofit organizations directly participate in the joint emergency response system without bidding to restrict inefficient self-learning. On the other hand, government should punish the speculative extra payoff of selfishness when airport adopts the reputation cooperation mechanism. Secondly, the airport emergency management institution should decrease supervised and managerial cost under bidding competition mechanism by using managerial skills and methods. Moreover, airport can sign an agreement with joint organizations to increase the risk-averse degree of them. For example, they can decrease punishment for bad coordination or increase their responsibility and social role. Thirdly, nonprofit organizations can make use of their special superiority and mechanism advantage. They can promote their reputation, power, and right to speak. Meanwhile, they also can decrease the speculative extra payoff and increase the probability of reputation cooperation mechanism. All above suggestions can help realize the Pareto state and harmonious coordination.

4. Conclusions

We study effects of risk-averse degree of participators in aviation joint emergency response considering the coevolution of cooperation mechanisms and individual preferences between airport and nonprofit organization. We put forward two mechanisms to select the joint nonprofit organization on the current aviation joint emergency mechanism in China and two preferences. We build replicator dynamics equations taking risk aversion attitude into account. Moreover, we introduce the factor of government. The results show that the larger the risk-averse degree is, the larger the probabilities of reputation cooperation mechanism and altruistic preference are. It can make the emergency environment more harmonious. Hence, government should make rules or subside actors for guiding and speeding up the harmonious evolution.

In theory aspect, this paper develops the evolutionary game between airport and nonprofit organization in aviation joint emergency response system. Meanwhile, it enlarges the research applications between public or private sector and nonprofit organizations. Moreover, we also introduce risk attitude factor to the evolutionary process. According to it, we compute the replicator dynamics equations by the conditional value-at-risk (CVaR) and study the effect of government intervention on evolution. It enriches relative researches on evolution of joint mechanism and emergency management. In practice aspect, this work can help actors to make decisions more accurately and efficiently. Moreover, it can instruct leaders to speed up evolutionary process for realizing Pareto state. In order to achieve the better management effect about disaster emergencies, we should pay more attention to risk attitudes and make sense of the effects on joint emergency response mechanisms.

However, in real environment, much information is uncertainty [37–40]. According to this situation, the randomness of effect scale in an aviation accident means the demand for coordination is stochastic. So, the random demand will be studied in the future. In this study, we consider risk-averse attitude for both actors. However, it is not difficult to image that the actors may be risk-taking. The risk attitude is related with accident probability. We will further research these problems in the future.

Competing Interests

The authors declare that they have no competing interests.

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References

[1] Y.-G. Feng and J. Wu, "Risk-averse newsvendor game model under emergency situations," *System Engineering Theory and Practice*, vol. 35, no. 3, pp. 598–607, 2015.

[2] X.-Y. Zhu and F. Luo, "Study on mechanism optimization of joint emergency response to aviation calamities in China," *China Safety Science Journal*, vol. 17, no. 6, pp. 5–11, 2007.

[3] T. Debbie, "Hazmat clean-up firm opens regional response center in North Salt Lake," *Enterprise/Salt Lake City*, vol. 36, no. 4, pp. 1–6, 2006.

[4] W. U. De-Sheng and L. I. Wei-An, "Interaction between formal contracts and informal contracts under random matching game," *Journal of Management Science in China*, vol. 13, no. 12, pp. 76–85, 2010.

[5] A. Abbasi, "Link formation pattern during emergency response network dynamics," *Natural Hazards*, vol. 71, no. 3, pp. 1957–1969, 2014.

[6] J. M. Smith and G. R. Price, "The logic of animal conflict," *Nature*, vol. 246, no. 5427, pp. 15–18, 1973.

[7] M. A. Nowak, A. Sasaki, C. Taylor, and D. Fudenherg, "Emergence of cooperation and evolutionary stability in finite populations," *Nature*, vol. 428, no. 6983, pp. 646–650, 2004.

[8] S. Faraj and Y. Xiao, "Coordination in fast-response organizations," *Management Science*, vol. 52, no. 8, pp. 1155–1169, 2006.

[9] N. Kapucu, "Public-nonprofit partnerships for collective action in dynamic contexts of emergencies," *Public Administration*, vol. 84, no. 1, pp. 205–220, 2006.

[10] Ö. Gürerk, B. Irlenbusch, and B. Rockenbach, "On cooperation in open communities," *Journal of Public Economics*, vol. 120, pp. 220–230, 2014.

[11] M. Perc and A. Szolnoki, "Co-evolutionary games—a mini review," *BioSystems*, vol. 99, no. 2, pp. 109–125, 2010.

[12] G. Szabó and A. Szolnoki, "Selfishness, fraternity, and other-regarding preference in spatial evolutionary games," *Journal of Theoretical Biology*, vol. 299, pp. 81–87, 2012.

[13] P. Buesser, J. Peña, E. Pestelacci, and M. Tomassini, "The influence of tie strength on evolutionary games on networks: an empirical investigation," *Physica A: Statistical Mechanics and Its Applications*, vol. 390, no. 23-24, pp. 4502–4513, 2011.

[14] H. Carlsen, L. Johansson, P. Wikman-Svahn, and K. H. Dreborg, "Co-evolutionary scenarios for creative prototyping of future robot systems for civil protection," *Technological Forecasting and Social Change*, vol. 84, pp. 93–100, 2014.

[15] L. Dehai and Y. Lijuan, "Equilibrium evolutionary analysis about city demolition emergency based scenario analysis," *Management Review*, vol. 24, no. 5, pp. 154–159, 2012.

[16] G. Li, Y.-G. Gu, and Z.-H. Song, "Evolution of cooperation on heterogeneous supply networks," *International Journal of Production Research*, vol. 51, no. 13, pp. 3894–3902, 2013.

[17] A. Abbasi, C. Owen, L. Hossain, and J. Hamra, "Social connectedness and adaptive team coordination during fire events," *Fire Safety Journal*, vol. 59, pp. 30–36, 2013.

[18] T. R. Roekafller and S. Uryasev, "Optimization of conditional value-at-risk," *Journal of Risk*, vol. 2, no. 3, pp. 21–41, 2000.

[19] R. T. Rockafellar and S. Uryasev, "Conditional value-at-risk for general loss distributions," *Journal of Banking and Finance*, vol. 26, no. 7, pp. 1443–1471, 2002.

[20] W. Jammernegg and P. Kischka, "Risk-averse and risk-taking newsvendors: a conditional expected value approach," *Review of Managerial Science*, vol. 1, no. 1, pp. 93–110, 2007.

[21] W. Jammernegg and P. Kischka, "Risk preferences and robust inventory decisions," *International Journal of Production Economics*, vol. 118, no. 1, pp. 269–274, 2009.

[22] W. Jammernegg and P. Kischka, "Risk preferences of a newsvendor with service and loss constraints," *International Journal of Production Economics*, vol. 143, no. 2, pp. 410–415, 2013.

[23] F. Wex, G. Schryen, S. Feuerriegel, and D. Neumann, "Emergency response in natural disaster management: allocation and scheduling of rescue units," *European Journal of Operational Research*, vol. 235, no. 3, pp. 697–708, 2014.

[24] R. Abounacer, M. Rekik, and J. Renaud, "An exact solution approach for multi-objective location-transportation problem for disaster response," *Computers and Operations Research*, vol. 41, no. 1, pp. 83–93, 2014.

[25] A. Bozorgi-Amiri, M. S. Jabalameli, and S. M. Mirzapour Al-e-Hashem, "A multi-objective robust stochastic programming model for disaster relief logistics under uncertainty," *OR Spectrum*, vol. 35, no. 4, pp. 905–933, 2013.

[26] X. Chen, Y. Zhang, T.-Z. Huang, and M. Perc, "Solving the collective-risk social dilemma with risky assets in well-mixed

and structured populations," *Physical Review E*, vol. 90, no. 5, Article ID 052823, 2014.

[27] X. Chen, A. Szolnoki, and M. Perc, "Averting group failures in collective-risk social dilemmas," *EPL*, vol. 99, pp. 1–6, 2012.

[28] C.-Y. Xia, S. M. Meloni, M. Perc, and Y. Moreno, "Dynamic instability of cooperation due to diverse activity patterns in evolutionary social dilemmas," *Europhysics Letters*, vol. 109, no. 5, Article ID 58002, pp. 1–6, 2015.

[29] H. Herlin and A. Pazirandeh, "Nonprofit organizations shaping the market of supplies," *International Journal of Production Economics*, vol. 139, no. 2, pp. 411–421, 2012.

[30] I. M. Nolte, E. C. Martin, and S. Boenigk, "Cross-sectoral coordination of disaster relief," *Public Management Review*, vol. 14, no. 6, pp. 707–730, 2012.

[31] W. L. Waugh Jr. and G. Straib, "Collaboration and leadership for effective emergency management," *Public Administration Review*, vol. 66, no. 1, pp. 131–140, 2006.

[32] J. M. Brinkerhoff, "Government-nonprofit partnership: a defining framework," *Public Administration and Development*, vol. 22, no. 1, pp. 19–30, 2002.

[33] K. Huang, "Co-evolution between individual preference and mechanisms: a new approach," *Research on institutional Economics*, no. 1, pp. 1–27, 2014.

[34] Y.-L. Liu, X.-X. Mei, and F. Sun, "Evolution path on the change of enterprises' international operational pattern based evolutionary game," *Xitong Gongcheng Lilun yu Shijian/System Engineering Theory and Practice*, vol. 35, no. 3, pp. 763–770, 2015.

[35] Y. Xu, B. Hu, and R. Qian, "Analysis on stability of strategic alliances based on stochastic evolutionary game including simulations," *System Engineering Theory and Practice*, vol. 31, no. 5, pp. 920–926, 2011.

[36] M. A. Nowak, "Five rules for the evolution of cooperation," *Science*, vol. 314, no. 5805, pp. 1560–1563, 2006.

[37] W. Pan, S. Liu, Y. Guo, and F. Wang, "Fuzzy multi-objective model for supplier selection considering multiple products in low carbon supply chain," *Environmental Engineering and Management Journal*, vol. 14, no. 8, 2015.

[38] W. Pan, F. Wang, Y. Guo, and S. Liu, "A fuzzy multiobjective model for supplier selection under considering stochastic demand in a supply chain," *Mathematical Problems in Engineering*, vol. 2015, Article ID 174585, 8 pages, 2015.

[39] W. Pan, L. Yu, S. Wang, and X. Wang, "A fuzzy multi-objective model for provider selection in data communication services with different QoS levels," *International Journal of Production Economics*, vol. 147, pp. 689–696, 2014.

[40] W. Pan, X. Wang, Y.-G. Zhong et al., "A fuzzy multi-objective model for capacity allocation and pricing policy of provider in data communication service with different QoS levels," *International Journal of Systems Science*, vol. 43, no. 6, pp. 1054–1063, 2012.