Research on Emergency Collaborative Incentives of Social Forces Participating in Public Emergencies from the Perspective of Smart City

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Abstract. Social forces are the backbone to participate in the emergency management of urban public emergencies. In the highly digitalized information environment of smart cities, there is insufficient motivation for social forces to participate in emergency management. To solve this problem, we proposed the incentive method of emergency coordination effect value, and constructed the incentive decision-making model of the government and social forces' master-slave emergency coordination cooperation. Finally, the MATLAB2018b software was used to simulate the case data. The research results showed that the level of effort input by social forces involved in emergency coordination was directly proportional to the value of emergency coordination. Compared with the situation where the government does not take incentives, the government's use of synergistic value incentives has significantly improved the power of social forces to participate in emergency coordination, and increased the benefits of social forces participating in emergencies. The incentive mechanism for the participation of social forces has been further improved and supplemented.

Keywords: social forces participation · synergy value · smart city · public emergencies · government incentives · Stackelberg game

1 Introduction

With the rapid development of information technology in recent years, smart cities have been continuously integrating, optimizing and improving urban management with the help of various network information technologies such as the Internet of Things, cloud computing, face recognition, geographic information systems, artificial intelligence, and big data mining and analysis. With the continuous development and application of smart cities, the mutual influence and dependence between various fields have gradually strengthened. This also promotes the accumulation of various unstable factors, making the number and complexity of public emergencies within the city worse. Therefore, in order to effectively respond and solve various problems caused by urban

Y. Chen et al. (Eds.): ICMETSS 2022, ASSEHR 693, pp. 25–37, 2023.
https://doi.org/10.2991/978-2-494069-45-9_5

emergencies, various intelligent application modules of smart cities have become technical means to solve urban public emergencies. The smart government module among them strengthens the connection between different emergency government groups and provides a more convenient communication platform for the information coordination of emergency management. However, it is still difficult to effectively solve urban emergency disasters or emergencies only by relying on emergency coordination among government organizations, and more social forces are needed. The "social forces" refer to companies, media, communities, and various forms of organizations spontaneously established in the process of social transformation, private voluntary teams and individual citizens, which are non-profit, non-governmental to a certain extent and social characteristics. Compared with government groups, these social power groups have more advantages in emergency resource distribution, emergency rescue time, and information on emergency scenes [1]. Therefore, in today's diversified development, facing the increasingly complex emergencies and emergency emergencies, giving full play to the advantages of social forces in responding to and resolving emergencies is of great significance to the emergency safety management of urban public emergencies.

The current research on the participation of social forces in the management of emergencies mainly focuses on three aspects. The first aspect is the evaluation and research of social participation in the management of emergencies. Wen, et al. (2016) [2] believed that social participation provided the necessary preconditions for the government's rescue work, which was conducive to ensure that the disaster-stricken people can rescue themselves as soon as possible. They also evaluated the current situation of social forces participating in urban natural disaster emergency management, and constructed the evaluation index system and evaluation model of social forces participating in urban natural disaster emergency management. Gao, et al. (2020) [3] believed that public participation was essential in the urban governance process of the smart city initiative. Therefore, big data analysis was conducted on the content of public network reviews of smart cities to reflect the statistics and spatial distribution of urban issues, as well as public opinion risk [4]. The second aspect is the study of social participation mechanisms. Wu, et al. (2020) [5] believed that effective social participation mechanisms can improve people's ability to respond to emergencies, especially in the short time after the emergencies, the scene was chaotic and the professional team fails to be timely upon arrival, and the social participation mechanisms of developed countries such as the United States, Japan, and Germany were compared and analyzed. The third aspect is the network research of social forces participating in emergency cooperation. Chen, et al. (2019) [6] believed that studying the forms of participation of social forces and network conditions would help promote the cooperation between social forces and the government and improve the adaptability of emergency systems. Therefore, social network analysis methods were used to determine the role and influence of social forces in emergency networks and analyze the factors. Mizrahi, et al. (2021) [7] studied the driving factors of trust in the emergency organization network, and believed that the public participates in emergency decision-making, and in extreme cases, the public would strongly demand to abandon government actions.

Based on the above literature review, it is recognized that the participation of social forces has a positive effect in emergencies. However, the effective participation of social

forces is still a key issue to be solved in the emergency management of public security crises. Whether it is to find deficiencies through evaluation methods, or to learn from the social participation mechanisms of other countries, or to analyze the network of cooperative organizations in social participation, and to analyze various influencing factors, although which can improve some of the problems in social participation, they does not take into account that social forces, as a non-governmental group, have strong social characteristics. In urban public emergencies, with the participation of different social entities such as non-governmental organizations, profit-making organizations, and the media, the lack of motivation to participate still leads to participation failures. The main way to deal with this problem effectively is to strengthen information sharing and improve the incentive and restraint mechanism [8].

In the context of smart cities, information sharing has been gradually improved, but the incentive and restraint mechanism for social participation still has shortcomings and needs to be improved. We mainly focus on the improvement of incentive mechanisms. In the current related research, scholars have proposed many a variety of incentive methods, common incentive methods mainly include moral incentives, material incentives, collective incentives, social incentives, etc. [9]. Some scholars in academia have proposed a new incentive method. Among them, White & Marchet, et al. (2021) [10] believed that the Digital Social Market (DSM), proposed based on the digital background of smart cities, can be regarded as a kind of service, which can be used in the context of sustainable-oriented urban services to motivate the public to participate. The advent of the digital era is not only improving the service functions of cities, but also promoting social forces to participate in the development of emergency coordination mechanisms. The advent of smart city information technology and digitization has strengthened the close connection between multiple entities in the aspect of emergency coordinated governance. Based on this, we also innovatively propose a new incentive method, that is, to encourage the synergistic value generated by the emergency synergy effect. On the one hand, the value generated by the synergy effect is still an effect value for the government that can reduce the emergency cost and increase the emergency income, and so is the social force participating in the emergency coordination. The government has seized this benefit value point for incentives, which can better promote the enthusiasm and initiative of social forces to participate in emergency coordination.

Therefore, based on the actual situation of social forces participating in the emergency coordination of public emergencies in smart cities, and the cooperation model of emergency coordination, we constructed an incentive decision model for the master-slave emergency coordination cooperation between the government and social forces to explore the impact of the value of the synergistic emergency effect on social forces' participation in efforts. To improve the emergency investment level of social forces, the emergency income goal of maximizing overall benefits can be realized.

2 Models and Methods

2.1 Problem Description

The smart functions of smart cities are realized, mainly based on network information technologies such as the Internet of Things and cloud computing, and the emergency

response also needs to rely on network information technology to achieve emergency governance coordination involving multiple parties. Therefore, in the emergency management system of a smart city, the emergency collaborative information exchange of different participants is mainly realized by the information transmission of network technology. Moreover, the government is in a dominant position, who is mainly responsible for the overall layout of emergencies and the coordination of information in various links. The social forces involved in the emergency are in a subordinate position, and multiple social forces share emergency tasks through emergency coordination in the emergency process. However, due to certain game competition and information asymmetry between various social forces, different social forces participating in emergency coordination are likely to form emergency information barriers before, resulting in low efficiency of information transmission, and even a low degree of coordination in some emergency work with overlapping content, or rejected on the grounds of non-responsibility, mutual perfunctory responsibilities, evasiveness, and other phenomena, resulting in some cross-cutting emergency work being shelved and ultimately unable to be effectively resolved, and finally being postponed indefinitely, causing greater losses. Therefore, in the emergency management system of the smart government, the government can adopt incentive strategies to change the degree of effort involved in emergency coordination of various social forces, and try to avoid the occurrence of the above problems.

2.2 Research Hypothesis and Symbol Description

To simplify the analysis, this study only discusses the master-slave emergency cooperation model of emergency management composed of one government and two social forces participating in emergency cooperation. In the model, there is a conflict of interests between them. It is assumed that the social forces participating in emergency coordination aim at maximizing their own interests, the government aims at maximizing the overall interests. In the absence of incentive and restraint mechanism, it is difficult for social forces to be willing to agree with the government in action. The emergency coordination among the participants is maintained through interests, and there is a stable and balanced interest game relationship among the game subjects [11]. Based on the above preconditions, we put forward the following assumptions.

Hypothesis 1: A single government is the leader and two social forces participating in emergency collaborative tasks are the followers in emergency collaborative governance, and the market position of the two social forces is the same. The government starts from the overall situation and takes the overall optimization as the goal to effectively stimulate and coordinate various social forces, while social forces cooperate in emergency response under the incentive and requirements of the government.

Hypothesis 2: When the government takes incentive measures to achieve the goal of maximizing the overall interests, various social forces play games and compete in order to obtain their own interests and strive to maximize their own interests. This game goal and effort behavior can be expressed by the level of emergency collaborative effort input.

Hypothesis 3: The emergency collaborative effort input level of social forces has a significant impact on emergency efficiency. Different emergency collaborative effort input level of social forces will not only affect their own interests, but also the interests

of the government. In the process of urban emergency response, in order to maximize the overall interests, the smart government, as the leader, reduces the total emergency cost or improves the output utility of emergency coordination input by improving the emergency coordination degree of various social forces.

Hypothesis 4: The value of emergency synergy is an important consideration in the incentive decision-making of smart government, and its impact on emergency benefits is significant. The value of emergency synergy makes the government and social forces willing to cooperate with each other together, and improve the stability of emergency synergy.

Multiple variables and related parameters will be involved in the paper. In order to facilitate analysis, it is necessary to explain in advance. Decision variables of master-slave emergency collaborative incentive for urban emergencies: 1) B is a control variable to motivate the government according to the value of synergy benefits generated by the emergency collaborative effort input level of social forces. 2) e_1, e_2 are the emergency collaborative effort input level of social force 1 and social force 2 respectively. 3) α_1, α_2 are the cost coefficient of emergency collaborative effort input level of social force 1 and social force 2 respectively. 4) β_0, β_1, β_2 are the distribution coefficient of emergency benefits output of smart government, social force 1 and social force 2 respectively, $\beta_0 + \beta_1 + \beta_2 = 1$. 5) λ_1, λ_2 are distribution Proportion of social force 1 and social force 2 incentives given by the government respectively, $\lambda_1 + \lambda_2 = 1$.

2.3 Model Construction

In smart city emergency management, one government and two social forces participating in emergency coordination and cooperation are considered, and there is a relationship of Stackelberg game between them. As the leader, the smart government first makes emergency information decisions and gives certain additional incentives to the social forces participating in emergency coordination through the smart emergency platform, so as to improve their effort input level of emergency coordination and make their behavior consistent with the goal of the smart government to maximize the overall interests. Therefore, the emergency coordination objective of smart city emergency information management platform can be expressed as:

$$Y = (e_1 + e_2 + ke_1 + ke_2 + ke_1e_2)\varepsilon \tag{1}$$

where ε is a random variable and the standard normal distribution obeyed, $\varepsilon > 0$, $E(\varepsilon) = 0, E(\varepsilon) = 1$. k represents the value coefficient of emergency synergy effect of social forces. The greater the coefficient, the greater the value of emergency synergy effect. $k = 0$ means that social forces participate in emergency synergy and have no information value.

The existence of synergy value will improve the emergency efficiency after the emergency subject obtains the value information, and will show the increasing characteristics of the emergency collaborative output function under certain conditions. Considering that in smart city emergency management, each emergency subject is often a complementary relationship rather than a substitute relationship. Therefore, the magnitude of

synergy is expressed in the form of multiply, ke_1, ke_2 represent the synergy value generated by social force 1, social force 2 and government emergency cooperation respectively. ke_1e_2 represents the value of synergy generated by emergency cooperation among social forces. According to the output function, the expected return of the government is expressed as:

$$U_G = \beta_0(e_1 + e_2 + ke_1 + ke_2 + ke_1e_2) - B \tag{2}$$

As the followers, social forces choose the of emergency cooperation effort input level to realize the goal of maximizing their own interests, according to the incentive intensity given by the government. Generally, the higher the effort input of social forces in emergency collaboration is, the greater the cost is. The cost function of emergency collaborative effort input of social force can be expressed as:

$$C(e_i) = \frac{1}{2}\alpha_i \frac{e_i^2}{1+k}, i = 1, 2 \tag{3}$$

From Eq. (3) we see that the cost function of emergency collaborative effort input is an upward curve, which means that the harder social forces work is, the greater the cost is. However, the greater the value information of collaborative benefit generated is, the more conducive the development of emergency collaborative tasks is. That is, the increase of the value coefficient of collaborative benefit will reduce the marginal cost of emergency effort input. The constant 1/2 is only set for the convenience of calculation and analysis, and changing any other normal number will not affect the analysis results. The expected benefits of social force can be expressed as:

$$U_{C_i} = \beta_i(e_1 + e_2 + ke_1 + ke_2 + ke_1e_2) + \lambda_i B - \frac{1}{2}\alpha_i \frac{e_i^2}{1+k}, i = 1, 2 \tag{4}$$

According to the government's expected benefits function, the government's objective function and its optimization problem can be expressed as:

$$maxU_G(e_1, e_2, B) = \beta_0(e_1 + e_2 + ke_1 + ke_2 + ke_1e_2) - B \tag{5}$$

$$s.t. \beta_0 + \beta_1 + \beta_2 = 1 \tag{6}$$

According to the hypothetical conditions, the smart government adopts different incentive intensity according to the collaborative benefit value of the respective emergency collaborative efforts of social forces. Thus, according to the expected benefits function of social forces, the objective function of social forces and its optimization problem can be expressed as follows:

$$maxU_{C_i}(e_1, e_2, B) = \beta_i(e_1 + e_2 + ke_1 + ke_2 + ke_1e_2) - \lambda_i B - \frac{1}{2}\alpha_i \frac{e_i^2}{1+k} \tag{7}$$

$$s.t. \beta_0 + \beta_1 + \beta_2 = 1, \lambda_i = \frac{e_i}{e_1 + e_2}, 0 \le \lambda_i \le 1, i = 1, 2 \tag{8}$$

3 Results and Discussion

3.1 Model Analysis

1) The government does take no incentives (B = 0). For comparison, firstly the equilibrium solution was analyzed when the government does give no additional bonus incentives to social forces. All social forces make independent decisions with the goal of maximizing their own interests. The optimization of social forces can be expressed as:

$$maxU_{C_i}(e_1, e_2, B) = \beta_i(e_1 + e_2 + ke_1 + ke_2 + ke_1e_2) - \frac{1}{2}\alpha_i\frac{e_i^2}{1+k} \tag{9}$$

$$s.t.\beta_0 + \beta_1 + \beta_2 = 1, i = 1, 2 \tag{10}$$

Lagrange function can be constructed as:

$$L_i = \beta_i(e_1 + e_2 + ke_1 + ke_2 + ke_1e_2) - \frac{1}{2}\alpha_i\frac{e_i^2}{1+k} + \mu(\beta_0 + \beta_1 + \beta_2 - 1), i = 1, 2 \tag{11}$$

From the first-order optimization condition, the optimal emergency collaborative effort input levels of social force 1 and social force 2 are respectively:

$$e_1^* = \frac{\beta_1(1+k)^2(\beta_2k^2 + \beta_2k + \alpha_2)}{\alpha_1\alpha_2 - \beta_1\beta_2(1+k)^2k^2} \tag{12}$$

$$e_2^* = \frac{\beta_2(1+k)^2(\beta_1k^2 + \beta_1k + \alpha_1)}{\alpha_1\alpha_2 - \beta_1\beta_2(1+k)^2k^2} \tag{13}$$

It can be seen from Eqs. (12) and (13) that when the distribution coefficient of emergency benefits output is known, the optimal emergency synergy effort input level of social forces depends on their emergency input cost coefficient α_1, α_2 and the value coefficient k of emergency synergy effect, that is, each social force considers the value of emergency synergy effect on the basis of measuring its own advantages or disadvantages of emergency investment cost relative to other social forces, and finally determines its own optimal emergency effort investment level.

2) When the smart government takes additional bonus incentive measures ($B > 0$) to make the participation of social forces in emergency coordination meet the overall interests, the social forces will adjust and determine the optimal investment level of emergency coordination efforts in pursuit of maximizing their own interests, according to the size of the bonus. The perfect equilibrium solution of the sub game of the model is obtained by backward induction.

The objective functions of social force 1 and social force 2 (i.e. Equations (7) and (8)) derive partial derivatives of e_1 and e_2 respectively, and the optimal first-order condition is:

$$\frac{\partial U_{C_1}}{\partial e_1} = \frac{Be_2}{(e_1+e_2)^2} + \beta_1(k+ke_2+1) - \frac{\alpha_1 e_1}{k+1} = 0 \tag{14}$$

$$\frac{\partial U_{C_2}}{\partial e_2} = \frac{Be_1}{(e_1+e_2)^2} + \beta_2(k+ke_1+1) - \frac{\alpha_2 e_2}{k+1} = 0 \tag{15}$$

From Eqs. (14) and (15):

$$B = \frac{(e_1+e_2)\left[\alpha_1 e_1 + \alpha_2 e_2 - (\beta_1+\beta_2)(1+k)^2 k(\beta_1 e_2 + \beta_2 e_1)\right]}{1+k} \tag{16}$$

Obviously, the optimal bonus incentive given by the government to social forces is not only related to the emergency input level of social forces, but also affected by the emergency input cost coefficient of social forces and the distribution coefficient of emergency income output.

Combining Eqs. (5), (6) and (16), the objective function of the government and its optimization problem can be further expressed as:

$$maxU_G(e_1,e_2,B) = \beta_0(e_1+e_2+ke_1+ke_2+ke_1e_2) - \frac{(e_1+e_2)\left[\alpha_1 e_1 + \alpha_2 e_2 - (\beta_1+\beta_2)(1+k)^2 k(\beta_1 e_2 + \beta_2 e_1)\right]}{1+k} \tag{17}$$

$$s.t. \beta_0 + \beta_1 + \beta_2 = 1 \tag{18}$$

The Nash equilibrium solution can be obtained as:

$$e_1^{**} = \frac{(1+k)^2[\alpha_1 - \alpha_2 + (2\beta_1 - 1)k(1+k)]}{(\alpha_1-\alpha_2)^2 - (k+1)\left[2k(\alpha_1+\alpha_2) + k^2(1+k)(4\beta_1\beta_2 - 1) - 4k(\alpha_1\beta_1 + \alpha_2\beta_2)\right]} \tag{19}$$

$$e_2^{**} = \frac{(1+k)^2[\alpha_2 - \alpha_1 + (2\beta_1 - 1)k(1+k)]}{(\alpha_2-\alpha_1)^2 - (k+1)\left[2k(\alpha_1+\alpha_2) + k^2(1+k)(4\beta_1\beta_2 - 1) - 4k(\alpha_1\beta_1 + \alpha_2\beta_2)\right]} \tag{20}$$

3.2 Numerical Analysis and Discussion

Smart city emergency collaborative governance is a complex system engineering, involving multiple links, which requires the cooperation and joint efforts of multiple participants. In the process of emergency coordination and cooperation, the government cannot fully supervise the behavior of each participant, and it is difficult to restrict the binding documents with similar contract terms. Therefore, only the government sets up a more effective incentive mechanism to promote each participant to work together, play a synergistic effect and achieve the goal of emergency coordination.

Assuming an emergency in a city, the government entrusts part of the emergency coordination tasks to two social forces according to the event attributes, and formulates corresponding incentive measures. In order to maximize the overall interests, the

Table 1. MODEL PARAMETER SETTING

α_1	α_2	β_0	β_1	β_2	k
0.8	0.8	0.4	0.3	0.3	(-1,1)
0.8	0.8	0.4	0.3	0.3	(0,7)
0.8	0.8	0.4	0.3	0.3	(0,15)
0.8	0.8	0.4	0.3	0.3	(-1,1)

government hopes to stimulate the emergency investment enthusiasm of the two social forces in the form of bonus incentive. See Table 1 for relevant parameters.

According to Table 1, Matlab2018b software was used for simulation calculation, and the results was analyzed as follows.

It can be seen from Fig. 1 that whether the government takes incentive measures for social forces or not, the emergency synergy effort input level of social forces increases, with the increase of the value of emergency synergy. Synergy makes the marginal benefits of emergency collaborative effort input level of one social force increase with the increase of emergency collaborative effort input level of another social force, so that both parties intend to cooperate and improve their emergency investment level. The greater the value of synergy, the stronger the intention of emergency collaborative cooperation. Under the same other conditions, the government's incentive to social forces can significantly improve the investment level of emergency efforts of social forces compared with the case without incentive. In addition, it can be found from the Fig. 1 that when $k > 0.6$, the incentive measures taken by the government play a significant role in improving the investment level of social forces' emergency efforts.

It can be seen from Fig. 2 that the benefit utility of social forces increases, with the increase of the value of emergency synergy. When the value of emergency synergy effect is not high, i.e. $k < 1$, due to the government's incentive measures, the benefit utility of social forces is larger than that in the non- incentive case. However, when $k > 1$, the benefit utility of social forces in the case of government incentive is smaller than that in the non-incentive case, with the increase of synergy effect value. This is because under the law of diminishing marginal cost and increasing marginal benefits of social forces' emergency input. And under the action of external incentives adopted by the government, the enthusiasm of social forces' emergency coordination is greatly improved. Due to the synergy value, more emergency costs are invested than under the no-incentives condition. When the value of emergency synergy is not high, the incentive effect of the government is not significant.

It can be seen from Fig. 3 that the government's revenue utility increases with the increase of the value of emergency synergy effect. When the government takes incentive measures, its revenue utility value is lower than that without incentive. The main reason is that the government's incentive of emergency synergy effect on social forces increases the government's emergency cost; In addition, the distance difference between the two curves is small, which may be due to the fact that the government is increasing the government's special emergency funds to stimulate social forces. At the same time, the

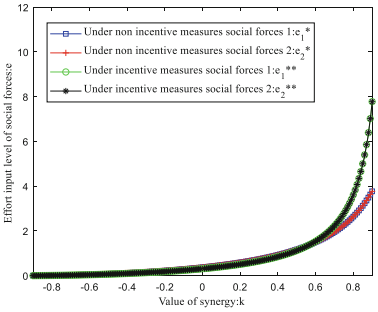

Fig. 1. The Curve of Relationship Between Synergy Value and Effort Investment Level of Social Forces

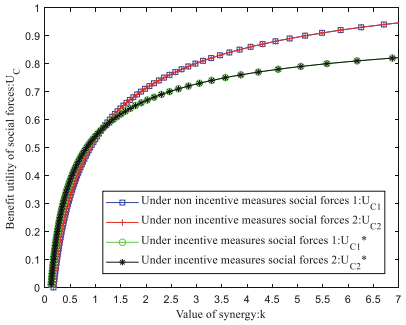

Fig. 2. The Curve of Relationship between Synergy Value and Benefit Utility of Social Forces

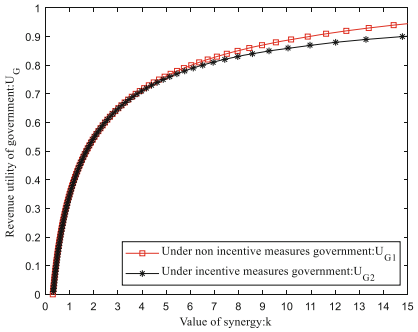

Fig. 3. The Curve of Relationship between Synergy Value and Benefit Utility of Smart Government

benefits of synergy are also distributed to social forces in the form of bonus incentive. So, how does the amount of bonus incentive of the government change?

As can be seen from Fig. 4, there are two different trends in the bonus incentive curve of the government according to whether the government encourages social forces or not. Firstly, when the government takes incentive measures, the bonus incentive curve

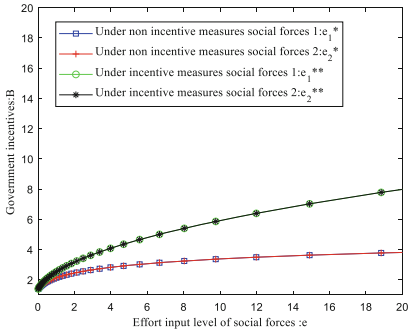

Fig. 4. The Curve of Relationship between Effort Investment Level of Social Forces and the Bonus Incentives of Smart Government

of the government shows an upward trend, and the rising rate is faster than that when the incentive is not taken. The main reason is that the level of emergency collaborative investment of social forces continues to improve, and the value of emergency collaborative benefits continues to increase, the amount of bonus incentives for the efforts of social forces by the government has been increasing. And the curve difference in two different cases should be the incentive value of the government using the special emergency fund. When the government does not take incentive measures, its bonus incentive curve shows a trend of rising first and then changing steadily. It is due to the continuous improvement of the level of emergency collaborative investment of social forces and the increasing value of emergency collaborative benefits, which increases the benefits of synergy to the government, and the government uses the benefits of synergy to increase the bonus incentive limit of the government. It is due to the lack of incentive measures by the government, which limited efforts of social forces in emergency coordination, the growth rate of emergency coordination benefits is slow.

4 Conclusions

According to the actual situation of emergency coordination in smart city, we analyzed the influencing factors of emergency coordination strategy selection, and discussed the impact of emergency coordination benefit value and government incentive on the willingness of social forces to participate in urban emergency coordination. On the basis of considering the government's attention to the value of emergency synergy, we constructed the incentive decision-making model of master-slave emergency synergy cooperation between the government and social forces, and discussed the synergy value and the impact of adopting bonus incentive on the emergency synergy investment level and benefits of social forces according to the comparison between whether the government sets bonus incentive or not. It is found that without bonus incentive, the emergency collaborative investment level of social forces and the revenue utility of the government increase with the increase of the value of the synergy effect. In the case of setting bonus incentives, the government takes the benefits brought by special emergency funds and synergy as the minimum incentive cost to promote social forces to invest more efforts,

improve the emergency investment level of social forces, and maximize the overall emergency target benefits.

This research enhanced the enthusiasm of social forces to participate in urban public emergency management by stimulating the value of synergy. Under the background of smart city, and the incentive mechanism for participation of social forces was further supplemented and improved. However, there are still deficiencies in this paper. It only considered the synergy value of social forces participating in cooperation as the same value coefficient k, and there is less consideration of the differences in the synergy of different social forces participating in emergency cooperation. Next, more attention will be paid to the differences of synergy effects of different social forces participating in urban public emergencies, for improving further the model parameters to study the impact mechanism of the value synergy of different social forces on the enthusiasm of social forces to participate in urban public emergency management.

Acknowledgment. This work was supported by the Major scientific and technological projects in Fujian Province (2019HZ07011-3); Fujian Social Science Planning Project (FJ2019B091); Scientific research startup fund of Fujian University of Technology (GY-S19013).

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