Emergency supplies requisition negotiation principle of government in disasters

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Abstract

Purpose – When disasters occur, the Chinese national or local government and their relevant departments (hereinafter referred to as the government) probably need to acquire emergency supplies from suppliers. Before concluding a transaction, the public officials usually negotiate the quality and price of the emergency supplies with the suppliers. They expect to achieve the best relief effect while the suppliers want to maximize their own interests. Therefore, in order to help the government acquire inexpensive emergency supplies with high quality in a short time, the purpose of this paper is to examine the negotiation process and proposes a negotiation principle for the staff.

Design/methodology/approach – This paper first elaborates the characteristics and impact factors of emergency supplies requisition negotiation. Then it establishes a model describing the negotiation on price and quality of emergency supplies between the public officials and suppliers. Afterwards, it proposes an algorithm which can estimate the success rate of the negotiation. Finally, the paper employs the conclusion of the model and algorithm to analyze the emergency supplies requisition negotiation process during the China Lushan earthquake.

Findings – This paper proposes a "WRAD" principle of emergency supplies requisition negotiation of public officials in disasters. First, they should ensure the requisition price is not too low. Second, they would widen the difference between the high price and low price. Third, it is best for them to follow the principle of "ascending negotiation and descending choice" while selecting multiple suppliers to negotiate.

Originality/value – This paper establishes a model to study the emergency supplies requisition negotiation process between the public officials and suppliers based on evolutionary game theory. The model assumes that both the public officials and suppliers are not fully rational individuals, and they need time to consult with each other to find out the optimal solution. This paper proposes an innovative action principle of the public officials during the negotiation process which can help it to acquire inexpensive, high-quality, emergency supplies within a short period from the suppliers.

Keywords Disaster, Game theory, Negotiation, Emergency management, Supplies requisition

Paper type Research paper

1. Introduction

The Chinese Government is responsible for ordering and storing some emergency supplies in advance for disaster relief. However, these emergency supplies may not be enough when a large-scale disaster occurs due to the limitations of the warehouse storage capacity and financial budget. Large-scale disasters refer to disasters which cause widespread damage and heavy casualties, such as earthquakes, tsunamis, etc.

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In these cases, the government must supplement supplies urgently to meet the relief demand within the shortest time. As a consequence, this paper aims to provide some approach to accelerate the process of emergency supplies requisition negotiation.

Emergency supplies are the basis of relief work in a disaster (Deo and Gurvich, 2011), and the allocation optimization of emergency supplies is essential during the emergency management process (Liu, 2004). Because the requirement of emergency supplies can be extremely large in major disasters (Wang *et al.*, 2009), it is of high importance to ensure the adequate inventory of emergency supplies and the timely feedback of the inventory shortages (Qin *et al.*, 2012). Moreover, increasingly more decision makers develop new approaches to purchase emergency supplies with the minimum amount of money based on the prediction of contingent events (Simonoff *et al.*, 2011). Therefore, it is valuable to study the issue of product requisition negotiation in emergency situations. The relevant literature focuses on either emergency materials requisition negotiation or utilization of game theory, especially evolutionary game theory, in product price negotiation.

1.1 Emergency materials requisition

Researchers have already established some models for this issue. Xu (2010, 2013) employed the newsvendor model to analyze the decisions made by risk-averse individuals. Nakano (2007) studied the electricity requisition negotiation in New York in emergency situations and proposed a method to reduce the impact of the emergency. Coles (1998) discussed the feasibility of using a process called "Comprehensive Spending Review" to develop a plan of requisition negotiation in emergency situations and made some recommendations. Kirsch (1993) studied the control of commodity prices in major disasters. Liang *et al.* (2012) proposed an option contract pricing model of emergency resources supply chain. Bagchi *et al.* (2011) discovered that the competition among bidders would increase the price of emergency materials; therefore, they proposed an optimal auction mechanism to minimize the game behavior. Ertem *et al.* (2010) designed an agent-based simulation of procurement auction framework to study the rescue behavior feature and its impact on the emergency materials requisition. However, most research objects in this area are significantly different from emergency supplies in types, demanders, and order procedures.

1.2 Utilization of game theory in product price negotiation

In recent years, most researchers have employed mathematical models to study the subject of product price negotiation, including multi-objective nonlinear programming (Rezaei and Davoodi, 2012), economic analysis (Vadde *et al.*, 2007), inventory theory (Cai *et al.*, 2013), and so forth. However, the most frequently used approach in requisition negotiation study is game theory. Specifically, by employing a static game model, George *et al.* (2009) elaborated the effect of competition on requisition negotiation and made a discount in the dual-channel supply chain. By using a dynamics game model, Niyato and Hossain (2008) solved the issue of spectrum price negotiation by suppliers in cognitive radio network. By establishing a repeated game model, Zhang and Ma (2012) explained the mechanism of price negotiation competition by four oligopolies based on the practical situation of Chinese property insurance market. By employing a cooperative game model, Yaiche *et al.* (2000) studied the price negotiation of different network rates in high-speed broadband network services. Cao *et al.* (2002) also applied the cooperative game theory in network services price negotiation.

However, the public officials and suppliers are all irrational decision makers. They need learning before choosing the optimal requisition negotiation strategy. This learning process can be described by the evolutionary game method. In fact, the evolutionary game theory is successfully used in the modeling of requisition negotiation. For example, based on the evolutionary game model, Zhao *et al.* (2012) simulated the optimal price negotiation strategy of bounded rational mobile virtual network operators in a duopoly market; Fan *et al.* (2013) studied the dynamics price negotiation and production planning issues in the uncooperative competitive market. The process of the emergency supplies requisition negotiation is a repeated bargaining process between both sides. Gerding and La Poutre (2006) established an evolutionary game model for a competitive market, where a buyer can try several sellers before making a purchase decision. They found that given the agents' number of remaining bargaining opportunities, the proposer has the advantage. Ji *et al.* (2015) developed an evolutionary game model to observe the cooperation tendency of multi-stakeholders. Eid *et al.* (2015) used evolutionary game theory approach to find an equilibrium profile of post-disaster insurance plans purchased by resident families and sold by insurance companies, as well as ex-post-disaster relief implemented by a government agency. Courtois and Tazdait (2012) considered the world made of "good" and "bad" suppliers and utilized the evolutionary game model to find that it admits a unique evolutionarily stable strategy: buyers may trust strangers if it is not too risky to do so.

Based on the analysis of literature above, we can draw a conclusion that research which focuses on emergency supplies requisition negotiation is still rare, and more importantly, the evolutionary game model can be employed in studying the requisition negotiation between public officials and suppliers.

According to the Emergency Response Law of the People's Republic of China, the preparation and transportation of emergency supplies is the responsibility of the national or local government and their relevant departments, depending on the severity of the disaster. In this paper, we refer to them as the government, because their responsibility and mode of work are nearly the same. In order to respond to major disasters, the Chinese National Procurement Center ordered various kinds of emergency supplies, such as cotton-padded clothes, quilts, rice, flour, candy, tents, disinfectants, and so forth. The purchase amount in 2010 was over 100 million RMB. All the emergency supplies were acquired and transported to the disaster areas in the stipulated time to make the relief process go smoothly.

Once a disaster occurs, the government first uses the inventory of emergency supplies and signs the option contracts with some suppliers before they get emergency supplies. If these still cannot meet the demand, the government should supplement the emergency supplies as soon as possible. Obviously, purchasing them from suppliers is usually required. However, if the quantity or quality of emergency supplies ordered from the suppliers are unable to meet the requirements, the government can call for public donations through the media or request assistance from other countries. Moreover, it has to negotiate with the suppliers as soon as possible due to the limited time frame. In general, it would try its best to make the transaction successful because looking for other suppliers delays time for the relief work. As a consequence, we obtain the emergency supplies supplementary process which is shown in Figure 1.

Emergency supplies are very different from general resources. Specifically, the demand elasticity of the government is very low. The emergency supplies are utilized to save lives, which cause the demand to be rigid. Additionally, the supply elasticity of the suppliers is also low. Once a supplier signs a contract with the government, it has to

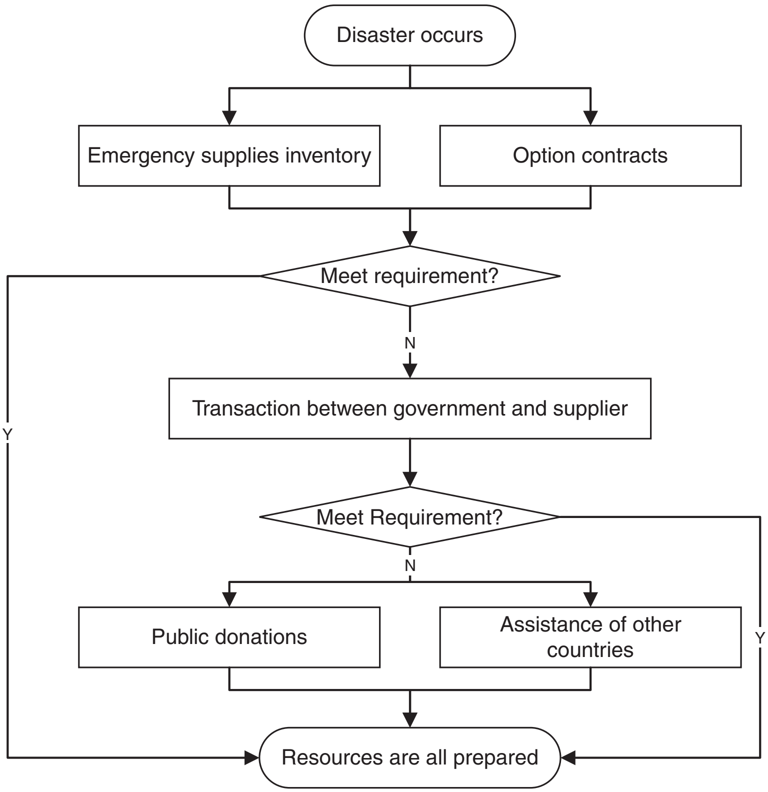

Figure 1. Emergency supplies supplementary process in China

make an effort to meet the requirement of the order due to the force of law, the government enforcement measures, and the reputation of the supplier itself. Differences of requisition negotiation between emergency supplies and general resources can be summarized as follows. First, time pressure during the emergency supplies requisition negotiation process is much heavier, because the time taken by the requisition negotiation is closely related to casualties (El-Anwar *et al.*, 2010). Second, the order price of the emergency supplies is usually higher, because the government cannot choose suppliers in a wide range (Liu and Xie, 2015). Third, the cost of the emergency supplies is probably higher, because overtime pay for the workers is needed while the suppliers prepare the emergency supplies (Wu *et al.*, 2015). Fourth, the failure of the emergency supplies requisition negotiation would lead to the delay of rescue time, which may result in a great loss; by contrast, loss caused by failure of negotiation of general resources is relatively lower (El-Anwar *et al.*, 2010). To summarize, the differences are listed in Table I.

Therefore, this paper establishes an evolutionary game model to analyze the emergency supplies requisition negotiation in disasters. The rest of this paper is organized as follows. The second section elaborates the features and impact factors of the emergency supplies requisition negotiation. The third section is divided into two parts. In the first part, it establishes the emergency supplies requisition negotiation model based on evolutionary game theory. In the second part, it proposes the emergency supplies requisition negotiation principle of the government based on the simulation results of the model. The fourth section utilizes the case of the China Lushan Earthquake to verify the rationality and practicability of the principle.

2. The impact factors of emergency supplies requisition negotiation

In recent years, the Chinese Government adopted a new ordering mode which is called "Quality First." In this mode, the government first announces the price of the emergency supplies; then, the suppliers submit the sample of its product; and finally, it examines whether the quality meets the requirement or not. Compared with the traditional mode that emphasizes only on the price of the emergency supplies, this new mode is more effective to find out good suppliers who can provide high-quality products and have strong supply capacity. In this mode, decision makers would determine a requisition price based on the capital budget which remains unchanged during the process of the emergency supplies requisition negotiation. Moreover, the quality of the emergency supplies is connected with their model or type provided by the supplier, which is very limited. The supplier chooses a model or type to negotiate the requisition price with the public officials.

The analysis of the following sections is based on this new ordering mode. Specifically, public officials and suppliers negotiate during the process of deciding the purchase price and product quality. The decision process is that the government announces a certain price to purchase the emergency supplies while the suppliers provide a quality level of them to sell, during which both sides get the maximum benefit.

The benefits of suppliers are the actual profit. Obviously, high price announced by the government, as well as low producing and transportation cost of emergency supplies, can lead to a high actual profit for the suppliers. Besides the two main factors above, the actual profit of the suppliers is also affected by other factors. The first one is the overtime pay. In particular, the requirement of emergency supplies by the government must be very urgent, which forces the suppliers to continue producing and transporting the products after working hours. Hence, overtime pay for the workers has to be taken into account. The second one is the probability of a successful transaction. Specifically, in case the government announces a low price while the suppliers provide high-quality products, the government would be willing to order a large volume of products. By contrast, when the government announces a high price and the suppliers provide high-quality products, the probability of acquisition is medium. However, if the suppliers provide low-quality products while the government announces a high price, the government may only order very few products, because the aim of the government for announcing a high price is to ask for goodwill on high-quality products. In addition, delivery speed of the suppliers is variable. Specifically, if the suppliers get much more money from the government, they are more willing to pay for accelerating the delivery speed.

Table I. Requisition negotiation differences between emergency supplies and general resources

	Emergency supplies	General resources
Time pressure	Heavy	Light
Order price	High	Low
Cost	High	Low
Loss by failure	High	Low

Although the government does not earn money during an emergency response process, it acquires rescue effect which is one of its most important responsibilities and is very helpful for enhancing its prestige. The payment of the government includes not only the cost of purchasing the emergency supplies but also the rescue time, which is much more important and can be considered as a special payment. Supplier's delivery speed is one of the most important impact factors of successful relief work. Additionally, no matter whether the quality of the emergency supplies is good or poor, a probability exists that they might be broken or cannot be used. On this occasion, public officials can contact the supplier to prepare new products and transport again. The process of the re-preparation and re-transportation could not only give rise to expenditure but also, much more importantly, waste precious rescue time. Moreover, if public officials fail in the negotiation with the current supplier, it should look for other ones immediately, which can also lead to rescue time delay.

3. The model of emergency supplies requisition negotiation

3.1 The evolutionary game model of the emergency supplies quality and price

The government must acquire emergency supplies as soon as possible after the occurrence of a major disaster. Based on the previous analysis, the public officials negotiate the quality and price of the emergency supplies with the suppliers. Specifically, the government announces a purchase price of the emergency supplies, while the supplier provides information about the quality of the emergency supplies to the government. After several rounds of negotiation, both sides decide whether to transact or not.

We suppose that there are two types of purchase price: high price and low price; there are also two types of emergency supplies quality: high quality and low quality. Similar approaches were employed in the research of Taylor and Day (2004) and Zeng *et al.* (2016). We also assume that "x" is the decision inclination of a supplier for "providing high-quality products"; "y" is the decision inclination of the government for "announcing a high price." In order to facilitate calculation, we use probability to represent decision inclination. Obviously, the larger the decision inclination is, the higher the probability should be. Based on the emergency supplies requisition negotiation characteristics elaborated in the last section, we can draw a conclusion as follows. The benefit of the suppliers is affected by the price and cost of the emergency supplies, overtime pay, and the probability of a successful transaction. The benefit of the government is affected by the price of the emergency supplies, the rescue effects, the delivery speed, probability and cost of re-transportation, cost of looking for another supplier, and probability of a successful transaction. Therefore, we propose the following assumptions:

Assumption 1. When the supplier provides emergency supplies with high quality and the government announces a high purchase price, the benefit of the supplier is as follows:

$$SGH = (p_1 - c_1 - V) \times W_1; \quad (1)$$

Assumption 2. When the supplier provides emergency supplies with high quality and the government announces a low purchase price, the benefit of the supplier is as follows:

$$SGL = (p_2 - c_1 - V) \times W_2; \quad (2)$$

Assumption 3. When the supplier provides emergency supplies with low quality and the government announces a high purchase price, the benefit of the supplier is as follows:

$$SPH = (p_1 - c_2 - V) \times W_3; \tag{3}$$

Assumption 4. When the supplier provides emergency supplies with low quality and the government announces a low purchase price, the benefit of the supplier is as follows:

$$SPL = (p_2 - c_2 - V) \times W_1; \tag{4}$$

Assumption 5. When the supplier provides emergency supplies with high quality and the government announces a high purchase price, the benefit of the government is as follows:

$$GHG = s_1 \times r_1 - p_1 - a \times b_1 - u \times (1 - W_1); \tag{5}$$

Assumption 6. When the supplier provides emergency supplies with high quality and the government announces a low purchase price, the benefit of the government is as follows:

$$GLG = s_2 \times r_1 - p_2 - a \times b_1 - u \times (1 - W_2); \tag{6}$$

Assumption 7. When the supplier provides emergency supplies with low quality and the government announces a high purchase price, the benefit of the government is as follows:

$$GHP = s_1 \times r_2 - p_1 - a \times b_2 - u \times (1 - W_3); \tag{7}$$

Assumption 8. When the supplier provides emergency supplies with low quality and the government announces a low purchase price, the benefit of the government is as follows:

$$GLP = s_2 \times r_2 - p_2 - a \times b_2 - u \times (1 - W_1). \tag{8}$$

The meanings of the parameters in the formulas above are described as follows: "p_1" and "p_2" represent the high price and low price, respectively, announced by the government; "c_1" and "c_2" are the costs of emergency supplies with high and low quality, respectively; "s_1" and "s_2" are the delivery speeds of the suppliers on the premise that the government announces a high and low price, respectively; and "r_1" and "r_2" are the rescue effects of the emergency supplies with high quality and those with low quality, respectively. Obviously, we have $p_1 > p_2$, $c_1 > c_2$, $s_1 > s_2$, and $r_1 > r_2$. "a" is the fee that the government pays when the emergency supplies are broken and need re-transportation. "b_1" and "b_2" are the probabilities that emergency supplies with high quality and those with low quality, respectively, cannot be used due to breakdown.

Generally, we have $0 < b_2 < b_1 < 1$. "u" is the fee paid by the government due to the decision that not ordering the emergency supplies produced by the current supplier and looking for other suppliers. "v" is the overtime pay by the supplier. "w_1" is the transaction volume in one of the following two cases: first, government announces a high price and supplier provides emergency supplies with high quality and second, government announces a low price and supplier provides emergency supplies with low quality. "w_2" is the transaction volume while government announces a low price and the supplier provides products with high quality. "w_3" is the transaction volume when the government announces a high price and supplier provides products with low quality:

H1. Based on the analysis in the last section, we obtain $s_1 > s_2$, $r_1 > r_2$, $0 < b_2 < b_1 < 1$, $w_2 > w_1 > w_3$, and $w_1 - w_3 > w_2 - w_1$. Additionally, we assume that the supplier is profitable by selling emergency supplies to the government. Otherwise, they will not participate in the negotiation (the charity case is an exception), which implies $p_1 > c_1 + v$ and $p_2 > c_2 + v$.

Because public officials and supplier are not entirely rational decision makers, they need time to learn before reaching the final stable strategy. Based on the hypothesis above, we employ the evolutionary game theory to analyze the requisition negotiation process of the emergency supplies between the public officials and supplier. We will discuss the evolutionary stable strategy of the supplier and public officials successively in the following part of this section.

3.1.1 The evolutionary stable strategy of the supplier. In case the supplier chooses to provide emergency supplies with high quality, its expected benefit is as follows:

$$ESG = y \times SGH + (1-y) \times SGL. \tag{9}$$

In case the supplier chooses to provide emergency supplies with low quality, its expected benefit is as follows:

$$ESP = y \times SPH + (1-y) \times SPL. \tag{10}$$

Therefore, the average benefit of the supplier is as follows:

$$EDS = x \times ESG + (1-x) \times ESP. \tag{11}$$

Let dx/dt be the change rate of possibility that the supplier chooses to provide emergency supplies with high quality. Then based on evolutionary game theory proposed by Weibull (1995), the replicator dynamics of x is as follows:

$$F(x) = \frac{dx}{dt} = x \times (ESG - EDS). \tag{12}$$

Thus, by substituting the formulas (1) and (4), (9)-(11) into the formula (12), we obtain the following:

$$\begin{aligned} F(x) = x(1-x)\{&y[(W_1 - W_3)(p_1 - c_2 - V) + (W_1 - W_2)(p_2 - c_1 - V)] \\ &-[(p_2 - V)(W_1 - W_2) + c_1 W_2 - c_2 W_1]\}. \end{aligned} \tag{13}$$

When the game reaches evolutionary stable equilibrium, x will not change with time, which implies F(x) = 0. Therefore, the game reaches evolutionary stable equilibrium when x = 0 or x = 1. Furthermore, a stable equilibrium can be defined as an evolutionary stable strategy only when it is robust to small perturbations. Based on this, we then discuss the evolutionary stable strategy of this game. If $y = ((p_2-V)(W_1-W_2)+c_1W_2-c_2W_1)/((W_1-W_3)(p_1-c_2-V)+(W_1-W_2)(p_2-c_1-V))$, then $F(x) = 0$. So all the values of x are evolutionary stable strategy on this occasion. If $y \neq ((p_2-V)(W_1-W_2)+c_1W_2-c_2W_1)/((W_1-W_3)(p_1-c_2-V)+(W_1-W_2)(p_2-c_1-V))$, because F(x) is continuous and differentiable, in order that x reaches evolutionary stable strategy, x should also satisfy the following:

$$\frac{dF(x)}{dx} = (1-2x)\{y[(W_1-W_3)(p_1-c_2-V)+(W_1-W_2)(p_2-c_1-V)] \\ -[(p_2-V)(W_1-W_2)+c_1W_2-c_2W_1]\} < 0. \tag{14}$$

Since:

$$\begin{cases} W_1-W_3 > W_2-W_1 \\ W_3 < W_1 < W_2 \\ p_1-c_2-V > p_2-c_1-V \end{cases},$$

we obtain:

$$(W_1-W_3)(p_1-c_2-V)+(W_1-W_2)(p_2-c_1-V) > 0. \tag{15}$$

Therefore if $(p_2-V)(W_1-W_2)+c_1W_2-c_2W_1 < 0$, which implies:

$$\frac{W_1}{W_2} < \frac{p_2-c_1-V}{p_2-c_2-V}, \tag{16}$$

we have:

$$y[(W_1-W_3)(p_1-c_2-V)+(W_1-W_2)(p_2-c_1-V)]-[(p_2-V)(W_1-W_2)+c_1W_2-c_2W_1] > 0.$$

So only when x = 1, the formula (14) holds. That is, x = 1 is the evolutionary stable strategy of the supplier. If:

$$\begin{cases} \frac{(p_2-V)(W_1-W_2)+c_1W_2-c_2W_1}{(W_1-W_3)(p_1-c_2-V)+(W_1-W_2)(p_2-c_1-V)} < 1 \\ (p_2-V)(W_1-W_2)+c_1W_2-c_2W_1 > 0 \end{cases},$$

the evolutionary stable strategy of the supplier is as follows:

$$\begin{cases} x = 0 & \text{if } y < \frac{(p_2-V)(W_1-W_2)+c_1W_2-c_2W_1}{(W_1-W_3)(p_1-c_2-V)+(W_1-W_2)(p_2-c_1-V)} \\ x = 1 & \text{otherwise} \end{cases}. \tag{17}$$

On this occasion, we have:

$$(p_2-V)(W_1-W_2)+c_1W_2-c_2W_1,$$

which implies:

$$\frac{W_1}{W_2} > \frac{p_2 - c_1 - V}{p_2 - c_2 - V}. \tag{18}$$

Since:

$$\frac{(p_2 - V)(W_1 - W_2) + c_1 W_2 - c_2 W_1}{(W_1 - W_3)(p_1 - c_2 - V) + (W_1 - W_2)(p_2 - c_1 - V)} < 1,$$

we obtain:

$$(-p_1 + c_1 + V)W_1 - 2(c_1 + V)W_2 + (p_1 - c_2 - V)W_3 < 0. \tag{19}$$

Then, we give a proof of the formula (19) as following.

Proof. Based on:

$$\begin{cases} W_1 - W_3 > W_2 - W_1 \\ W_3 < W_1 < W_2 \end{cases},$$

we obtain:

$$\begin{aligned} &(-p_1 + c_1 + V)W_1 - 2(c_1 + V)W_2 + (p_1 - c_2 - V)W_3 < (-p_1 + c_1 + V)W_1 \\ &-(c_1 + V)W_1 - (c_1 + V)W_3 + (p_1 - c_2 - V)W_3 = -p_1 W_1 + (p_1 - c_1 - c_2 - 2V)W_3 \\ &< -p_1 W_3 + (p_1 - c_1 - c_2 - 2V)W_3 = (-c_1 - c_2 - 2V)W_3 < 0. \end{aligned}$$

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3.1.2 The evolutionary stable strategy of the government. In case government chooses to announce high price, its expected benefit is as follows:

$$EGH = x \times GHG + (1 - x) \times GHP. \tag{20}$$

In case the government chooses to announce low price, its expected benefit is as follows:

$$EGL = x \times GLG + (1 - x) \times GLP. \tag{21}$$

Therefore, the average benefit of the government is as follows:

$$EDG = y \times EGH + (1 - y) \times EGL. \tag{22}$$

Let dy/dt be the change rate of possibility that the government chooses to announce high price, then the replicator dynamics of y is as follows:

$$F(y) = \frac{dy}{dt} = y \times (EGH - EDG). \tag{23}$$

Then, by substituting the formulas (5)-(8) and (20)-(22) into the formula (23), we obtain:

$$\begin{aligned} F(y) = \frac{dy}{dt} = y(1 - y)\{&[(s_1 - s_2)(r_1 - r_2) + (2W_1 - W_2 - W_3)u]x \\ &- [p_1 - p_2 - (s_1 - s_2)r_2 + u(W_1 - W_3)]\}. \end{aligned}$$

When the game reaches evolutionary stable equilibrium, y will not change with time, which implies F(y) = 0. Therefore, the game reaches evolutionary stable equilibrium when y = 0 or y = 1. Moreover, a stable equilibrium can be defined as an evolutionary stable strategy only when it is robust to small perturbations. Based on this, we then discuss the evolutionary stable strategy of this game. If: $x = (p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3))/((s_1-s_2)(r_1-r_2)+(2W_1-W_2-W_3)u)$, then $F(y)\equiv 0$. So all the values of y are an evolutionary stable strategy on this occasion. If: $x \neq (p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3))/((s_1-s_2)(r_1-r_2)+(2W_1-W_2-W_3)u)$, because F(y) is continuous and differentiable, in order that y reaches evolutionary stable strategy, y also satisfies:

$$\frac{dF(y)}{dt} = (1-2y)\{[(s_1-s_2)(r_1-r_2)+(2W_1-W_2-W_3)u]x - [p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3)]\} < 0. \tag{24}$$

Based on:

$$\begin{cases} W_1-W_3 > W_2-W_1 \\ W_3 < W_1 < W_2 \end{cases},$$

we can make a discussion as follows: if $p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3) < 0$, which implies:

$$W_1-W_3 < \frac{(s_1-s_2)r_2-p_1+p_2}{u}, \tag{25}$$

we obtain:

$$[(s_1-s_2)(r_1-r_2)+(2W_1-W_2-W_3)u]x-[p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3)] > 0.$$

So only when y = 1, the formula (23) will be true. That is, y = 1 is the evolutionary stable strategy of the supplier.

If:

$$\begin{cases} p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3) > 0 \\ \frac{p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3)}{(s_1-s_2)(r_1-r_2)+(2W_1-W_2-W_3)u} < 1 \end{cases},$$

which implies:

$$\begin{cases} W_1-W_3 > \frac{(s_1-s_2)r_2-p_1+p_2}{u} \\ W_2-W_1 < \frac{(s_1-s_2)r_1-p_1+p_2}{u} \end{cases}, \tag{26}$$

the evolutionary stable strategy of the government is as follows:

$$\begin{cases} y = 0, & \text{if } x < \frac{p_1-p_2-(s_1-s_2)r_2+u(W_1-W_3)}{(s_1-s_2)(r_1-r_2)+(2W_1-W_2-W_3)u} \\ y = 1, & \text{otherwise} \end{cases}. \tag{27}$$

if $(p_1 - p_2 - (s_1 - s_2)r_2 + u(W_1 - W_3))/((s_1 - s_2)(r_1 - r_2) + (2W_1 - W_2 - W_3)u) > 1$, which implies:

$$W_2 - W_1 > \frac{(s_1 - s_2)r_1 - p_1 + p_2}{u}, \tag{28}$$

we obtain:

$$[(s_1 - s_2)(r_1 - r_2) + (2W_1 - W_2 - W_3)u]x - [p_1 - p_2 - (s_1 - s_2)r_2 + u(W_1 - W_3)] < 0.$$

So only when y = 0, the formula (24) holds. That is, y = 0 is the evolutionary stable strategy of the government.

To sum up, we suppose that neither the government nor the supplier has an inclination in the initial time, which means x = 0.5 and y = 0.5. Based on the formulas (16) and (17), if the government wants to ensure that supplier k provides emergency supplies with high quality, it should satisfy:

$$\frac{W_{k1}}{W_{k2}} < \frac{p_{k2} - c_{k1} - V_k}{p_{k2} - c_{k2} - V_k},$$

or:

$$\begin{cases} \frac{W_{k1}}{W_{k2}} > \frac{p_{k2} - c_{k1} - V_k}{p_{k2} - c_{k2} - V_k} \\ \frac{(p_{k2} - V_k)(W_{k1} - W_{k2}) + c_{k1}W_{k2} - c_{k2}W_{k1}}{(W_{k1} - W_{k3})(p_{k1} - c_{k2} - V_k) + (W_{k1} - W_{k2})(p_{k2} - c_{k1} - V_k)} < \frac{1}{2} \end{cases},$$

which implies:

$$P_{k2} > \frac{W_{k2}c_{k1} - W_{k1}c_{k2}}{W_{k2} - W_{k1}} + V_k. \tag{29}$$

Based on the formula (26), if the government wants to ensure that the purchase price is low (27) and (28), it should satisfy:

$$\begin{cases} W_{k1} - W_{k3} > \frac{(s_{k1} - s_{k2})r_{k2} - p_{k1} + p_{k2}}{u_k} \\ W_{k2} - W_{k1} < \frac{(s_{k1} - s_{k2})r_{k1} - p_{k1} + p_{k2}}{u_k} \\ \frac{p_{k1} - p_{k2} - (s_{k1} - s_{k2})r_{k2} + u_k(W_{k1} - W_{k3})}{(s_{k1} - s_{k2})(r_{k1} - r_{k2}) + (2W_{k1} - W_{k2} - W_{k3})u} > \frac{1}{2} \end{cases},$$

or:

$$W_{k2} - W_{k1} > \frac{(s_{k1} - s_{k2})r_{k1} - p_{k1} + p_{k2}}{u_k},$$

which implies:

$$p_{k1} - p_{k2} > \frac{1}{2}(s_{k1} - s_{k2})(r_{k1} + r_{k2}) + (W_{k1} - W_{k2})u_k. \tag{30}$$

Therefore, we can draw a conclusion from the formulas (29) and (30) as follows: if the government wants to obtain emergency supplies with high quality at a low purchase price, the high price and low price announced by it should be:

$$\begin{cases} p_{k1} = \frac{1}{2}(s_{k1} - s_{k2})(r_{k1} + r_{k2}) + (W_{k1} - W_{k2})u_k + \frac{W_{k2}c_{k1} - W_{k1}c_{k2}}{W_{k2} - W_{k1}} + V_k \\ p_{k2} = \frac{W_{k2}c_{k1} - W_{k1}c_{k2}}{W_{k2} - W_{k1}} + V_k \end{cases}. \tag{31}$$

3.2 Analysis of the evolutionary game model

First, we examine the decision-making principles of the supplier. From the formula (16), we can see that if w_1 is much lower than w_2, the supplier will choose to provide high-quality emergency resources. From the formulas (17) and (18), we can see that if w_1 and w_2 are nearly equal, the supplier will either provide high-quality emergency resources or provide low-quality ones. That is, when the government announces the low price, if the expected transaction volume of high-quality resources is much larger than that of low-quality ones, the suppliers are stimulated to provide high-quality resources regardless of the relatively high cost. From the formula (17), we can see that if p_1 is considerably larger than p_2, which implies that there is a large gap between the high price and the low price, the supplier will be stimulated to provide high-quality emergency resources. Therefore, we can draw a conclusion as follows: the government putting up order price can stimulate the supplier to provide high-quality emergency resources; large expected transaction volume can significantly make the suppliers eager to provide high-quality emergency resources.

Second, we analyze the decision-making principles of the public officials. From the formula (25), we can see that if w_1 and w_3 are nearly equal, the government will choose to announce high price to purchase the emergency resources. It can be explained that when the government thinks the supplier is likely to provide low-quality resources, it tends to announce high price to stimulate the supplier to provide high-quality resources. From the formulas (26) and (27), we can see that if w_1 is much higher than w_3 and the difference between w_2 and w_1 are near equal, the government can announce either the high price or the low price. From the formula (28), we can find that if w_2 is much larger than w_1, the government will announce low price to purchase emergency resources. It is because that when the public officials believe that the supplier will provide high-quality resources, it will reduce the price to lower the expenses. From the formula (27), we can see that if the effect of the rescue effort by the high-quality emergency resources is much higher than that by the low-quality ones, the government will be more likely to announce high price to purchase emergency resources. Therefore, we can draw a conclusion as follows: if the quality difference of the resources is very significant or the public officials know the supplier is likely to provide low-quality resources, the government will announce high price to ensure that high-quality resources can be acquired. If the public officials are not sure which type of resources the supplier will provide, it will not reduce order price.

3.3 The success rate determination model of emergency supplies requisition negotiation

The success rate of the emergency supplies requisition negotiation among the public officials and supplies is not a constant value due to the different situations of the suppliers. It is affected by the following factors: supply capacities of the suppliers, the requirement of the government, the previous successful negotiation number of the government, etc.

We suppose that during the relief process in a disaster, the government needs m units of a particular type of emergency supplies. Meanwhile, there are in total K suppliers which can provide this kind of emergency supplies. The volumes of emergency supplies which the suppliers can provide are $n_1, n_2, \ldots, n_K$, respectively. Moreover, we assume $n_1 > n_2 > \ldots > n_K$. The public officials negotiate with these suppliers successively.

The negotiation success rate of supplier k is supposed as:

$$W_{ki} = g_{ki} W_k, i = 1,\ 2,\ 3; \tag{32}$$

in which g_{ki} is called "transaction probability coefficient." Based on the previous assumption $w_{k2} > w_{k1} > w_{k3} > 0$ and $w_{k1}\text{-}w_{k3} > w_{k2}\text{-}w_{k1}$, we obtain $g_{k2} > g_{k1} > g_{k3} > 0$ and $g_{k1}\text{-}g_{k3} > g_{k2}\text{-}g_{k1}$. In order to facilitate calculation, we order $g_{1i} = g_{2i} = \ldots = g_{ki} = g_i$. w_k is called "basic probability of successful transaction" in this paper and it satisfies:

$$\begin{cases} W_k = \frac{n_k}{m} \times \frac{\sum_{j=1}^{K} n_j}{\sum_{j=2}^{K} n_j}, \text{ if } k = 1 \\ W_k = \frac{n_k}{m - \sum_{j=1}^{k-1} W_j n_j} \times \frac{\sum_{j=1}^{K} n_j}{\sum_{j=k+1}^{K} n_j}, \text{ if } \ k > 1 \end{cases}. \tag{33}$$

Based on the formulas (32) and (33), we can calculate w_{ki} which is the successful negotiation probability of supplier k.

Specifically, the Nash equilibrium point of the negotiation between the public officials and the supplier which is the ultimately determined quality and the purchase price of the emergency supplies can be obtained by the model proposed in the last section. Therefore, we obtain the success rate that the public officials negotiate with multiple suppliers as follows:

$$\begin{cases} W_{ki} = g_i \times \frac{n_k}{m} \times \frac{\sum_{j=1}^{K} n_j}{\sum_{j=2}^{K} n_j}, \text{ if } \ k = 1 \\ W_{ki} = g_i \times \frac{n_k}{m - \sum_{j=1}^{k-1} W_j n_j} \times \frac{\sum_{j=1}^{K} n_j}{\sum_{j=k+1}^{K} n_j}, \text{ if } \ k > 1 \end{cases}. \tag{34}$$

Based on the formula (34), we have:

$$\frac{W_{(k+1)i}}{W_{ki}} = \frac{n_{k+1}}{n_k} \times \frac{m - \sum_{j=1}^{k-1} n_j W_{ji}}{m - \sum_{j=1}^{k} n_j W_{ji}} \times \frac{\sum_{j=k+1}^{K} n_j}{\sum_{j=k+2}^{K} n_j}. \tag{35}$$

We view n_{k+1} as the only continuous variable in the formula (35), then we order:

$$f(n_{k+1}) = \frac{W_{(k+1)i}}{W_{ki}}.$$

While $f(n_{k+1})$ is derivable, we obtain:

$$\frac{df(n_{k+1})}{dn_{k+1}} > 0.$$

Therefore, $f(n_{k+1})$ is a monotone increasing function. Furthermore, we have:

$$\begin{cases} \frac{W_{(k+1)i}}{W_{ki}} \geqslant 1, \text{if } n_{k+1} \geqslant \frac{n_k\left(m-\sum_{j=1}^{k} n_j W_{ji}\right)\left(\sum_{j=k+1}^{K} n_j\right)}{\left(m-\sum_{j=1}^{k-1} n_j W_{ji}\right)\left(\sum_{j=k+1}^{K} n_j\right)+n_k\left(m-\sum_{j=1}^{k} n_j W_{ji}\right)} \\ \frac{W_{(k+1)i}}{W_{ki}} < 1, \text{ if } n_{k+1} < \frac{n_k\left(m-\sum_{j=1}^{k} n_j W_{ji}\right)\left(\sum_{j=k+1}^{K} n_j\right)}{\left(m-\sum_{j=1}^{k-1} n_j W_{ji}\right)\left(\sum_{j=k+1}^{K} n_j\right)+n_k\left(m-\sum_{j=1}^{k} n_j W_{ji}\right)} \end{cases}. \quad (36)$$

As can be seen from the formula (36), when the public officials negotiate with multiple suppliers successively, if the public officials want to make the negotiation success rate increase, it must ensure that the supply capacity of the current supplier is not lower than a threshold value. In this case, the condition of emergency supplies requisition negotiation ending at the zth supplier is as follows: (1) the total supply of the former z-1 suppliers, which has been negotiated, is less than the actual demand; (2) the difference between this total supply and actual demand is less than the supply capacity of the zth supplier; and (3) the negotiation between the public officials and the zth supplier is successful. Consequently, the probability of emergency supplies requisition negotiation ending at the zth supplier is as follows:

$$p_z = P\{so_z > m, so_z - n_z < m\} \times W_{zi}.$$

4. The principle of the government in the emergency supplies requisition negotiation

In the emergency supplies requisition negotiation, the government would make effort to achieve three objectives including (1) acquiring emergency supplies with high quality, (2) paying a relatively low price, and (3) accomplishing the negotiation in a short time. Theoretically, we can use the formula (31) to calculate the optimal high price and low price that the government should announce in the negotiation. However, some parameters in this formula cannot be obtained accurately and need estimations by experts; some require plenty of time to determine, even though they are possible to be acquired eventually. Moreover, the success rate of the negotiation between the public officials and each supplier is insignificant for the government to take an action. As a consequence, in the major disaster scenario, it is more practical to summarize an action principle of the public officials in the emergency supplies requisition negotiation. In case the public officials could only negotiate with one supplier at a time, based on the analysis in the last section, we propose a "WRAD" action principle of the government in the emergency supplies requisition negotiation, which includes the following three aspects:

(1) Widen the difference between the high price and low price. We can draw a conclusion from the formula (30) that the government makes the difference between the high price and low price not less than a threshold value. While

announcing a high price and low price, the government can assert a claim about the minimum quality level of the emergency supplies. Thus, by widening the difference between the two prices, the government can conveniently acquire emergency supplies with good quality at a reasonable price.

(2) Raise the low price. It can be concluded from the formula (29) that the government should ensure that the low price announced is not lower than a threshold value. In fact, the main purpose of the suppliers for providing emergency supplies is to make profit. Consequently, if the price announced by the government is reasonable, the negotiation between them should be smooth. Additionally, the government announcing a high price would probably encourage the suppliers to provide emergency supplies with high quality.

(3) Ascending negotiation and Descending choice. The formula (36) indicates that if the supply capacity of a supplier is greater than a threshold value, the negotiation success rate of it must be higher than that of the former supplier. Moreover, we can draw a simpler conclusion that if the supply capacity of the latter supplier is stronger than that of the former one, then the negotiation between the latter one is more likely to succeed. Additionally, provided that the suppliers are sequenced by supply capacity from weak to strong, the public officials chooses the weakest supplier to start a negotiation. In this case, the success rate of the strongest supplier would be approaching 100 percent, although this is generally not the most time-saving practice. In order to shorten the total time consumption of the negotiation, the public officials can negotiate with the suppliers with high supply capacity soon and ensure a relatively high success rate. Based on this, we propose a balanced approach to select suppliers. This approach is divided into several rounds while each round consists of the following four steps. First, arrange all the suppliers in the selection pool by supply capacity from strong to weak. Second, select several suppliers starting from the one with the strongest supply capacity till the total supply not lower than the demand. Third, negotiate with the selected suppliers from the one with the lowest supply capacity to the one with the strongest supply capacity. Fourth, if the negotiation with these supplies is not completely successful, then remove these suppliers from the selection pool and return to the first step. Repeat these four steps for several rounds until the emergency supplies requirement is satisfied.

For example, the public officials arrange all the suppliers by supply capacity from strong to weak and number them as “1,” “2,” “3” and so on. Afterward, the public officials start to select from the first supplier. The total supply is just not lower than the demand m when the public officials select until the ath supplier. Then, the public officials negotiate from the ath supplier backward to the first one. Unfortunately, negotiations with some suppliers failed, which causes a gap of emergency supplies. Therefore, the public officials select from the (a+1)th supplier to the bth supplier until the gap is filled. Subsequently, the public officials negotiate from the bth supplier backward to the (a+1)th supplier. If the negotiation is not completely successful, the public officials must select the rest of the suppliers to negotiate until the emergency supplies demand is satisfied. As a conclusion, the suppliers selecting and negotiating principle of the public officials is drawn in Figure 2.

5. Case study

A magnitude 7.0 earthquake hit Lushan County (Latitude 30.3 and longitude 103.0) in Ya'an city in China at 8:02a.m. on April 20th, 2013. A total of 196 people were killed in the earthquake. Because the storage of tents cannot meet the requirement, the government decides to purchase ten thousand tents from suppliers immediately. While negotiating with the suppliers, the government can follow the "WRAD" principle. Specifically, it must widen the difference between the high price and low price, raise the low price, and follow the principle of "ascending negotiation and descending choice" while negotiating with multiple suppliers. If there is enough time to calculate and relevant data are easy to acquire, the government can calculate the optimal high price and low price, as well as the success rate of the negotiation with each supplier, using the algorithm proposed previously.

We assume that there are two types of tents which are high-quality tents and low-quality tents, while the costs of them are \$20,000 and \$10,000, respectively. Because the supplier requires workers to continue producing and delivering products after working hours, it must pay workers \$10,000 for overtime work. If the tent is broken, the government has to pay for an extra \$20,000 to re-transport new tents. The probability is 0.1 that a high-quality tent is broken. The probability is 0.2 that a low-quality tent is broken. If the government decides not to purchase tents from the current supplier and lavish rescue time to search for other potential suppliers, the equivalent economic loss is \$300,000. Compared with the low-quality tents, the high-quality ones are more likely to ensure the safety of the victims. Moreover, the successful rescue effort can be considered as the most important benefit of the government. So the tents with high quality and those with low quality can bring the benefit of \$500,000 and \$400,000 to the government, respectively. Moreover, if the government announces a high price, the suppliers may be more active for the transaction and accelerate the delivery speed. We convert the delivery speed into a parameter of actual rescue effect of the tent. Afterward, we set the parameter as 1 or 0.7 for high-price condition or low-price condition, respectively. Transaction probability coefficients in various conditions are set as $g_1 = 0.8$, $g_2 = 0.9$, and $g_3 = 0.1$. Additionally, we suppose that there are ten suppliers with different supply capacities. The supply capacities of them are 40, 37, 33, 30, 27, 23, 20, 17, 13, and 10 thousand, respectively. They are numbered from 1 to 10 consecutively.

In this case, the total supply of the first to third supplier exceeds the demand. So the public officials negotiate with the third, second, and first supplier consecutively.

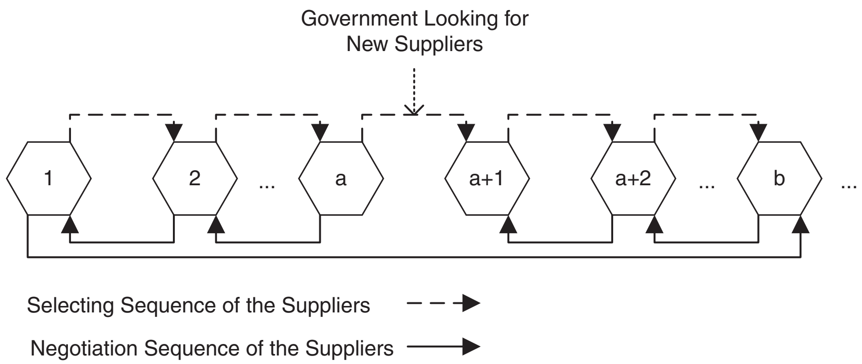

Figure 2.
Suppliers selecting and negotiating principle of the government

If the government wants to purchase a low-price tent and acquire tents with high quality, the optimal high price and low price which is announced by the government are listed in Table II. The success rates of the negotiation with suppliers are also shown in Table II.

We suppose that the public officials succeeds at negotiation with the first supplier but fails at the negotiations with the second supplier and the third supplier. Therefore, it has to conduct another round of negotiation. Because the gap between the supply and demand is 70, the public officials choose the fourth, fifth, and sixth suppliers to negotiate. Similarly, we can calculate the success rate, low price and high price of this round based on the formulas (36) and (31). The calculation results are listed in Table III.

If the supply of tent still does not meet the demand after this round, the public officials must conduct a new round of negotiation. The success rate, low price and high price of the new round can be obtained similarly.

6. Conclusions

This paper first elaborates the characteristics and impact factors of emergency resources requisition negotiation, then establishes a model of emergency resources requisition negotiation. Based on the analysis of this model, this paper proposes the "WRAD" principle of the government in the emergency supplies requisition negotiation. Specifically, the government can widen the difference between the high price and low price, raise the low price, and follow the principle of "ascending negotiation and descending choice" while negotiating with multiple suppliers. The "WRAD" principle may be followed by the government if it wants to purchase emergency supplies with high quality at a low price in a short time. In case that relative data are easy to acquire, the government can employ the algorithm to calculate the optimal high price and low price that is announced, as well as the success rate of the negotiation with each supplier. Therefore, the research result of this paper is practical to the emergency supplies preparation in disasters. However, the factors that affect emergency supplies requisition negotiation and the affecting mechanism are more sophisticated than the hypothesis proposed in this paper. Consequently, adding more factors and complicating the influencing mechanism can be considered in further researches. Moreover, in order to make the research results precise, instead of the only qualitative, considering different emergency supplies requisition source and utilizing the system simulation approach are valuable research topics.

	3rd supplier	2nd supplier	1st supplier
Success rate	0.27	0.38	0.62
Low price	9	7.6	7.8
High price	21.6	19.6	18.9

Table II. The calculation result of the first round of negotiation

	6th supplier	5th supplier	4th supplier
Success rate	0.30	0.50	0.80
Low price	7.5	7.1	8
High price	19.8	18.5	18.5

Table III. The calculation result of the second round of negotiation

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Further reading

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