Option Reserve Model of Emergency Materials for Government and Enterprises Under Rotation Based on Numerical Calculation

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Abstract. The emergency materials reserve faces the risk of shortage and waste of expiration at the same time. Combined with the phenomenon that the government attaches great importance to the measures of emergency materials rotation, this paper first establishes the model of government's separate emergency supplies reserve under rotation (RGSR) and proves that the reserve quantity of government is greater than that in the government's separate emergency supplies reserve without rotation (GSR). Then, the paper puts forward the option reserve model of government and enterprise emergency materials under rotation (RGEOR), and proves that under RGEOR the government can reduce the self-stored materials but increase the total reserve, so as to reduce the pressure of government reserve under the condition of ensuring the emergency support capacity. Finally, a numerical experiment is given to analyze the impact of rotation on supplier's profit and the reserve quantity of government.

Keywords: emergency materials alteration · option contracts · government enterprise joint reserve · numerical calculation

1 Introduction

At present, emergency management capacity still has great deficiencies, especially since the outbreak of COVID-19, which has exposed the outstanding problem of insufficient strength in strengthening the management of emergency and disaster relief supplies. Since the outbreak of COVID-19, the management of emergency and disaster relief supplies has been raised to a new historical level. The emergency material reserve is faced with the uncertainty of demand quantity and demand time. On the one hand, if the emergency demand is large, the reserve of emergency supplies may not be able to meet the emergency demand, resulting in a shortage of supplies, and then the disaster losses can't be effectively controlled. On the other hand, due to the low probability of demand for emergency materials and the limitation of the shelf life of materials, if the government reserves a large amount of materials, once the demand does not occur or is small within the shelf life, financial resources will be wasted due to material loss. The situation indicates that the emergency materials reserve is facing the risk of shortage

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and overdue waste at the same time. At present, the main emergency materials reserve method is the government's separate reserve, which puts forward high requirements for the government's reserve capacity and causes high reserve costs. To find a more efficient and scientific way to reserve emergency materials and solve the current problems such as single form of reserve emergency materials, backward means of reserve, idle and waste of resources, insufficient support capacity and so on are the difficulties faced in the process of reserve emergency materials.

Under the background that the government encourages the government and enterprises to jointly reserve emergency materials, the academic community has tried to research the multiple enterprise joint reserve strategy, including the advance payment, flexible quantities, option contracts, outsourcing and so on [1, 2, 4, 11]. The option contract, the American option contract especially, ensures that the option buyer can execute the option at any time during the contract period, which plays a very good role in dealing with the uncertainty of the demand for emergency supplies and the demand time.

By introducing the option contracts into the government-enterprise joint reserve emergency supplies procurement model, the procurement pricing and coordination issues in the option contract have been studied [12], on this basis the influence of the supply capacity of the spot market and the occurrence time of emergencies on the decision-making of both government and enterprise has been analyzed [8]. In the single option purchase mechanism, the option contract between government and enterprise can effectively improve the guarantee capacity of the emergency system and reduce the unit emergency guarantee cost of the government [6]. In the multiple procurement mechanism under option contracts, there is an emergency material guarantee mechanism, which can balance the cost and efficiency of emergency supplies supply [9].

In the above studies, there are few studies on the disposal of surplus materials stored by the government itself. The current disposal methods of surplus materials are mainly humanitarian donation strategy, buyback strategy and put option contracts [3]. Regarding the management of self-stored materials by the government, the Chinese government attaches great importance to the material rotation system in the actual emergency reserve. For example, the *Regulations on Emergency Support for Emergencies in Shandong Province* and the *Implementation Rules for the Dynamic Transfer of Public Health Emergency Medical Reserve Materials in Weifang* have all explained the rotation. It can be found that the rotation of emergency supplies has been gradually implemented in the actual stockpile of government emergency supplies.

In the academic field, there is still a lack of relevant research on emergency material rotation. In view of whether the emergency supplies should be rotated, a qualitative research on the reasons, bottlenecks and countermeasures of the rotation reserve mechanism not yet established in our army have been conducted [5], and the conditions under which suppliers will implement rotation has been analyzed [13]. In response to the problem of how to implement the rotation of emergency materials, the calculation method for the rotation period of various types of war readiness material has been given [14]. Based on the value loss characteristics of emergency supplies, the optimal rotation strategy of three different types of emergency supplies has been discussed [10]. In addition, a rotation system between national reserves and hospitals has been established, and the conditions and specific strategies for rotation have been put forward [7].

It can be seen that the current academic research on the rotation of emergency materials mainly focuses on whether the rotation strategy, and there is a lack of relevant research on the rotation in the decision-making of government-enterprise joint emergency materials reserve. Therefore, combined with the current research status of the joint reserve of emergency materials under the government-enterprise option contract and the current situation of the rotation operation practice in the process of government reserve, this paper studies the issue of the government-enterprise emergency materials option reserve under the rotation.

2 Model

2.1 Model Description

The existing emergency supplies option procurement studies consider an emergency supplies supply chain composed of a government and a supplier. At the beginning of the reserve period, the government purchases Q physical materials from suppliers and stores them in the emergency reserve. At the same time, government and the supplier sign a call option contract, stipulating that the government purchases q option materials from the supplier. In case of demand, materials shall be used in the order of the government reserves first and then the options. When the materials in the government's emergency reserve are insufficient, call option shall be executed to purchase physical materials of no more than q from the supplier. If all reserves still can't meet demand, the government makes emergency purchases on the spot market. At the end of the reserve period, when the physical reserves of the government has surplus, the government will deal with it and get the corresponding residual value benefits. If the government doesn't exercise the call option, the supplier will get the residual value of q option materials. The government and the supplier seek to maximize profits throughout the reserve period. The specific procurement process is shown in Fig. 1.

The basic process of RGEOR remains unchanged, but the method of handling the surplus supplies is changed through the rotation of materials. During the reserve period, the supplier will arrange rotation for the Q materials stored by the government when the period of validity reaches half. During the entire reserve period, the government reserves Q effective materials. At the end of the period, the Q materials reserved by the government are unconditionally transferred to the suppliers, and the suppliers refund the corresponding payment. For q option materials, the supplier incorporates the reserved option materials into the normal business circulation system of the enterprise, and dynamically updates the inventory to keep it always within the shelf life. During the reserve period, the Q materials that the supplier helps the government to rotate and the q materials that are rotated by themselves are connected to the market at wholesale prices, and the profits belong to the suppliers. During the entire reserve period, both the government and suppliers pursue the maximization of their profits. The government's profit is the social benefit brought by the reduction of casualties and property losses due to the reserve of sufficient emergency supplies when a sudden disaster occurs.

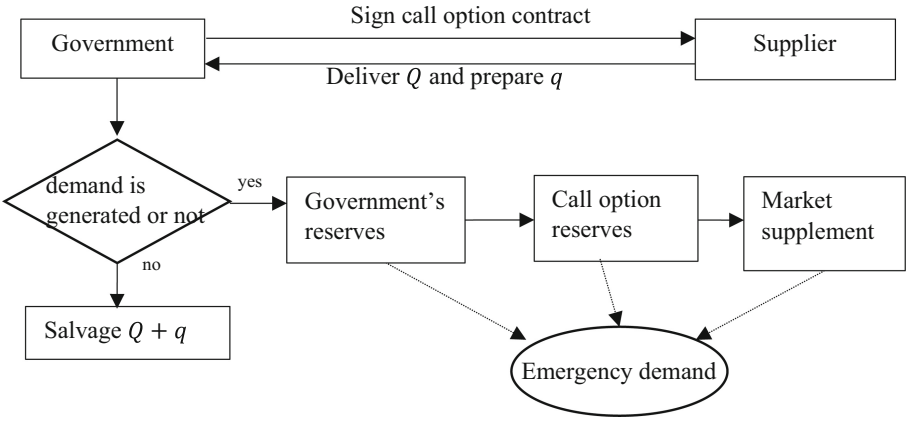

Fig. 1. Procurement process of government-enterprise option materials without rotation.

2.2 Symbol Description and Assumptions

X: the probability distribution function of demand, $F(x)$ the probability distribution function of demand, $f(x)$ is the probability density function of demand, the maximum value is M, and the mean value is μ;

o: option premium per option contract;

ω: wholesale price of government reserves;

c: unit material production cost;

c_r: rotation cost of per unit government supplies;

c_u: rotation cost of per unit option material;

e: strike price of the call option;

Q: government's physical reserves;

q: the amount of call option materials;

v: residual value of per unit emergency supplies;

p: expected market purchase price of the unit material;

u: social benefit conversion coefficient of unit material.

To ensure the rationality of the model, the size relationship between parameters is as follows:

$v < c < \omega < e < p < u$: Only when the production cost of materials is less than the wholesale price of materials purchased by the government, the transaction can be concluded. Only when the strike price is greater than the wholesale price and less than the market price, the government will sign the option contract.

$o + e < \omega + 2c_r$: The cost paid by the government for each unit of option materials should be less than the cost of each unit of self-stored materials, otherwise the government will not sign the option contract.

$o + v < c$: The sum of residual value and option fee shall be less than the material production cost of the suppliers, otherwise the enterprise can provide materials without restriction.

$e + o < p$: Otherwise, the government will not provide option contracts, but directly choose to purchase materials from the spot market when demand occurs to make up for the shortage.

$\omega > c + c_u$: Otherwise, the supplier will not to assist the government to complete the rotation of government self-stored materials.

At the same time, the model conforms to the following assumptions:

Assumption 1: In order to analyze the effect of the model from the perspective of market mechanism, the government should not acquire emergency materials by political footwork;

Assumption 2: There is only one buyer (government) and one supplier, and they sign a single period contract, and the rotation period is equal to the shelf life of emergency materials;

Assumption 3: Market procurement can meet the demand of emergency materials;

Assumption 4: Only one emergency occurs in a contract period.

3 Benchmark Model

The government separate reserve of emergency supplies (GSR) is the most common emergency material reserve method at present, and this paper uses it as the benchmark model. When the rotation is not considered, the government purchases Q_ω emergency supplies from suppliers at the wholesale price ω at the beginning of the period and reserves them in the government reserve. If $0 < x < Q_\omega$, the remaining materials shall be treated as residual value. If $x \geq Q_\omega$, the government needs to urgently purchase $(x - Q_\omega)$ materials from the market. In the whole process, both the government and suppliers pursue the maximization of their own profits. Then, the government's expected revenue function is:

$$\begin{aligned}\Pi_{\omega g} &= \int_0^Q [ux - \omega Q + v(Q - x)]f(x)dx \\ &\quad + \int_Q^M [ux - \omega Q - p(x - Q)]f(x)dx \\ &= (u - p)M + pQ - \omega Q - u\int_0^M F(x)dx \\ &\quad + v\int_0^Q F(x)dx + p\int_Q^M F(x)dx\end{aligned} \tag{1}$$

Solve the first-order and second-order derivatives of Q in Eq. (1), and get the point where there is a maximum government revenue, and the optimal purchase amount is $Q_\omega^* = F^{-1}(\frac{p-\omega}{p-v})$. At this time, the expected revenue of the government and the expected revenue of the supplier are:

$$\begin{aligned}\Pi_{\omega g}\big|_{Q_\omega = Q_\omega^*} &= (u - p)M + pQ_\omega^* \\ &\quad - \omega Q_\omega^* - u\int_0^M F(x)dx \\ &\quad + v\int_0^{Q_\omega^*} F(x)dx + p\int_{Q_\omega^*}^M F(x)dx\end{aligned} \tag{2}$$

$$\Pi_{\omega s}\big|_{Q_\omega = Q_\omega^*} = (\omega - c)Q_\omega^* \tag{3}$$

Figure 2 and Fig. 3 show the rotation process of materials in the model of government's separate emergency supplies reserve under rotation (RGSR). The government

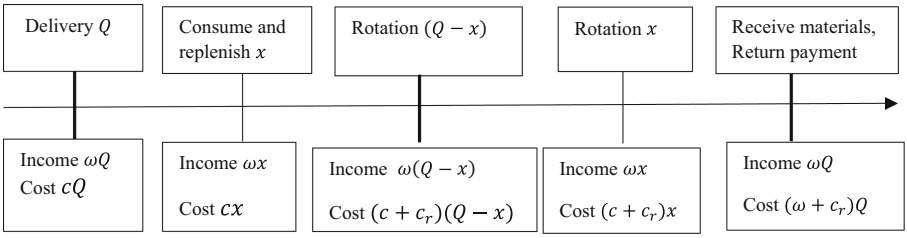

Fig. 2. Material rotation process and supplier's benefit when reserves are sufficient.

pays for rotation cost of self-stored materials, including the material rotation fee in the mid-term and the fee incurred when the supplier unconditionally accepts the materials at the end of the period. When $0 < x < Q$ o r $Q \leq x$, the rotation processes of government reserves throughout the contract period are shown in Fig. 2 and Fig. 3.

In the case of sufficient and insufficient reserves, when the demand occurs in the second half of the reserve period, the rotation process is the same as that in the first half. The replenishment process in the rotation process ignores the replenishment time interval, that is, it is assumed that the instant replenishment. Therefore, the government's expected revenue function in RGSR is:

$$\begin{aligned}\Pi_{\omega g}^{U} &= \int_0^Q (ux - \omega x - 2c_r Q) f(x)dx \\ &\quad + \int_Q^M [ux - \omega Q - 2c_r Q - p(x-Q)] f(x)dx \\ &= (u-p)M + pQ - \omega Q - 2c_r Q \\ &\quad - u\int_0^M F(x)dx + \omega \int_0^Q F(x)dx + p\int_Q^M F(x)dx\end{aligned} \tag{4}$$

Solve the first-order and second-order derivatives of Q in Eq. (4), and get the point where there is a maximum government revenue, and the optimal purchase amount is $Q_\omega^{U*} = F^{-1}(\frac{p-\omega-2c_r}{p-\omega})$. At this time, the expected revenue of the government and the supplier are:

$$\begin{aligned}\Pi_{\omega g}^{U}\Big|_{Q_\omega^U = Q_\omega^{U*}} &= (u-p)M + pQ_\omega^{U*} \\ &\quad - \omega Q_\omega^{U*} - 2c_r Q_\omega^{U*} - u\int_0^M F(x)dx \\ &\quad + \omega \int_0^{Q_\omega^{U*}} F(x)dx + p\int_{Q_\omega^{U*}}^M F(x)dx\end{aligned} \tag{5}$$

$$\begin{aligned}&\Pi_{\omega s}^{U}\Big|_{Q_\omega^U = Q_\omega^{U*}} \\ &= \int_0^Q [2\omega Q_\omega^{U*} - 2cQ_\omega^{U*} + (\omega - c)x] f(x)dx \\ &\quad + \int_Q^M (3\omega Q_\omega^{U*} - 3cQ_\omega^{U*}) f(x)dx \\ &= 3\omega Q_\omega^{U*} - 3cQ_\omega^{U*} - (\omega - c)\int_0^{Q_\omega^{U*}} F(x)dx\end{aligned} \tag{6}$$

Proposition 1. When $c_r < \overline{c_r}$, the rotation operation can increase the government's reserve of emergency supplies, where $\overline{c_r} = \frac{(p-\omega)(\omega-\nu)}{2(p-\nu)}$.

Proposition 1 indicates that the government does not have to bear the value loss of overdue materials under rotation, but it needs to pay a certain cost for rotation operation.

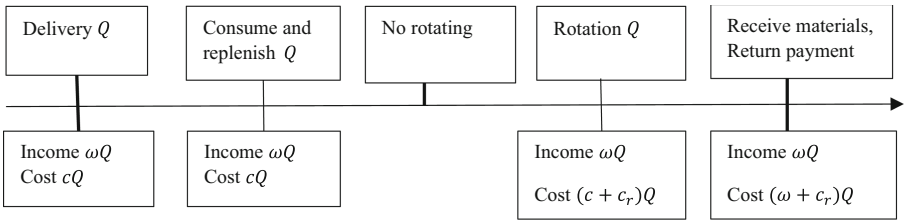

Fig. 3. Material rotation process and supplier's benefit when reserves are insufficient.

If c_r is enough little, the government's purchase quantity will be higher than that without rotation; otherwise, if the cost of rotation is too high, the government's purchase quantity will not be higher than that without rotation.

4 The Decision of Government in RGEOR

In the government-enterprise joint option materials procurement model under the rotation (RGEOR), the supplier's rotation process for the government's self-stored materials during the contract period is shown in Fig. 2 and Fig. 3. After the rotation, all materials can be sold at wholesale prices. This process ignores government's inventory management cost and supplier's inventory management cost, but considers the cost of rotation. For the option materials stored by the supplier, they are included in the normal business circulation system of the company for rotation. In this case, the supplier quotes parameters such as wholesale price, option premium, and strike price in the RGEOR, and the government decides whether to cooperate with the supplier and q and Q.

The government's expected revenue function is:

$$\begin{aligned} U_g = & \int_0^Q (ux - \omega x - 2c_r Q - oq) f(x) dx \\ & + \int_Q^{Q+q} [ux - \omega Q - 2c_r Q - oq \\ & - e(x - Q)] f(x) dx \\ & + \int_{Q+q}^M [(u - p)x - (\omega + 2c_r - p)Q \\ & - (o + e - p)q] f(x) dx \\ = & (u - p)M + (p - \omega - 2c_r)Q \\ & + (p - e - o)q - u \int_0^M F(x) dx + \omega \int_0^Q F(x) dx \\ & + e \int_Q^{Q+q} F(x) dx + p \int_{Q+q}^M F(x) dx \end{aligned} \tag{7}$$

Solving the first-order and second-order derivatives of Q and q in Eq. (7), we get that the government's revenue function is a convex function, and there is a maximum revenue value. The quantity of optimal self-reserve is $Q_r^* = F^{-1}(\frac{o+e-\omega-2c_r}{e-\omega})$, and the optimal option purchase quantity is $q_r^* = F^{-1}(\frac{p-e-o}{p-e}) - Q$.

The supplier's expected revenue function is:

$$\begin{aligned} U_s = & \int_0^Q [2\omega Q - 2cQ + (\omega - c)x \\ & + (o + \omega - c - c_u)q) f(x)dx \\ & + \int_Q^{Q+q} [3\omega Q - 3cQ + oq - cq \\ & - c_u q + e(x - Q) + \omega(Q + q - x)] f(x)dx \\ & + \int_{Q+q}^{M} [3\omega Q - 3cQ + oq \\ & - cq + eq - c_u q f(x)dx \\ = & \ 3\omega Q - 3cQ + oq - cq + eq - c_u q \\ & - (\omega - c) \int_0^Q F(x)dx - (e - \omega) \int_Q^{Q+q} F(x)dx \end{aligned} \tag{8}$$

Proposition 2. When the supplier's quotation is satisfied $\frac{o(p-\omega)}{p-e} < 2c_r$, the RGEOR is established.

If both the government and the enterprise are willing to sign an option contract, then $0 < F(Q_r^*) < F(Q_r^* + q_r^*) \leq 1$, because $F(x)$ is an increasing function, so $\frac{o+e-\omega-2c_r}{e-\omega} < \frac{p-e-o}{p-e} < 1$, then $\frac{o(p-\omega)}{p-e} < 2c_r$ can be calculated. Proposition 2 shows that the cost of rotation operation is crucial to whether the government and the enterprise can sign the option contract. The government has to bear the rotation cost of the replacement of self-stored materials. If the rotation cost and the option premium and option strike price can't meet the condition $\frac{o(p-\omega)}{p-e} < 2c_r$, the government will not sign an option contract with the supplier, but prefer to reserve materials alone. When the cost brought by the option contract is lower than the rotation cost, the government is more willing to sign the option contract and share the reserve task by the supplier.

Proposition 3. When the RGEOR is established, the total reserve of government supplies must be greater than RGSR.

When $Q_r^* + q_r^* > Q_\omega^{U*}$, there is $\frac{o}{p-e} < \frac{2c_r}{p-\omega}$. Combined with the conditions for the establishment of RGEOR in Proposition 2, we conclude that when RGEOR is established, the total reserve of government materials must be greater than RGSR.

Proposition 3 illustrates the superiority of RGEOR, which can ensure the increase of the total reserve of government emergency supplies under this mode, that is, the government's emergency material support capability for emergencies is enhanced. At the same time, we also note that option premium, option strike price, wholesale price and cost of rotation are important parameters affecting whether the government and suppliers can achieve cooperation. Therefore, if the government wants to increase the reserves, it should select suppliers with strong inventory management ability, so that the rotation cost will reduce, and the reserves will increase. At the same time, we can conclude from the conditional expression that the supplier's rotation cost will decrease, and at least one parameter of wholesale price, option premium and option strike price will decrease.

Proposition 4. Compared with RGSR, when $\frac{o(p-\omega)}{p-e} < 2c_r$, the government's self-stored materials in RGEOR decrease, but the total reserves increase.

When $Q_r^* < Q_\omega^{U*}$, then $\frac{2c_r-o}{e-\omega} > \frac{2c_r}{p-\omega}$, $\frac{o(p-\omega)}{p-e} < 2c_r$ can be calculated. Combining Proposition 2 and Proposition 3, when $\frac{o(p-\omega)}{p-e} < 2c_r$, the government's self-stored materials in RGEOR are smaller than the RGSR, but the total reserve is larger than that in RGSR.

Proposition 4 shows that RGEOR can't only reduce the self-reserve of government supplies but also increase the total reserve. By adjusting the contract parameters, the pressure of the limited reserve capacity of government can be relieved on the premise of ensuring the guarantee ability of emergency supplies, and the value of the option contract can be truly played.

5 Numerical Experiment

For suppliers, as long as the revenue brought by the reserve model proposed by the government is higher than that of GSR, then they will cooperate with the government. Therefore, the change of suppliers' revenue under different modes and the government's choice of reserve modes are discussed in Section 5. Suppose a government purchases a batch of emergency supplies from a supplier of emergency supplies. The demand for emergency supplies follows an exponential distribution, with a mean of 1 000 and $U = 10000$. Relevant parameters are assumed as $c = 40$, $o = 2$, $e = 70$, $p = 80$, $u = 100$, $v = 10$, $c_r = 5$, $c_u = 2$.

Figure 4 reflects the relationship between the wholesale price and government reserve quantity Q in GSR and RGSR. It is obvious that the quantity of government emergency material reserves in RGSR is significantly higher than that in GSR. This phenomenon is mainly because the rotation operation alleviates the problem of capital loss caused by the expiration of materials, although the government needs to pay certain costs for rotation operation, but as long as the rotation cost meets $c_r < \overline{c_r}$, the government will gain some benefits from the operation of rotation. Therefore, under the condition of a certain wholesale price, the government will increase the amount of reserves under rotation.

Figure 5 reflects the relationship between wholesale price ω and supplier's income in the three reserve modes. It can be clearly seen that the income of suppliers in RGSR

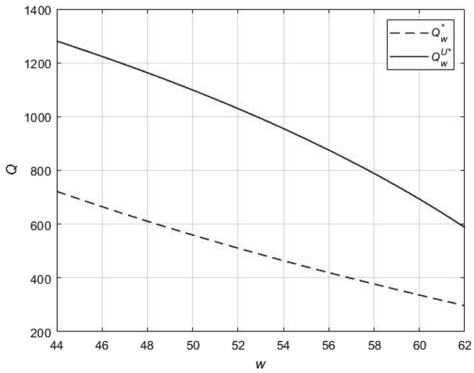

Fig. 4. The change of purchase volume with wholesale price in GSR and RGSR.

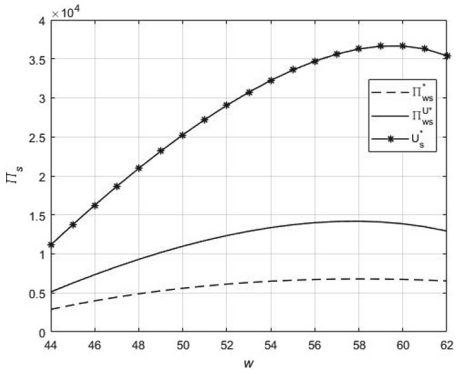

Fig. 5. The change in supplier income with wholesale prices in the three models.

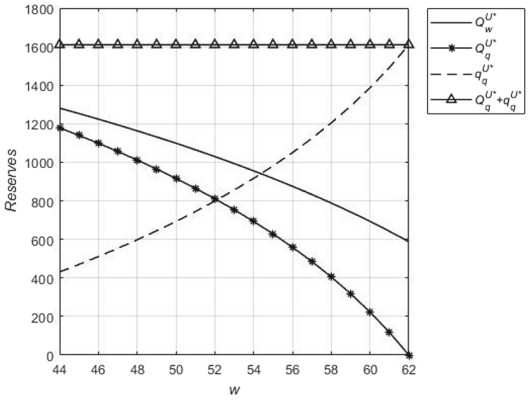

Fig. 6. The change of reserve with wholesale price in RGSR and RGEOR

is much higher than that of GSR, mainly because rotation operations increases the supplier's order volume, which makes its sales revenue significantly increase. At the same time it also means that the supplier is more willing to sign procurement contracts under rotation with the government. Meanwhile, supplier's profit in RGEOR is higher than that of RGSR, which also means that with or without option contract, suppliers' profit will increase under rotation. Therefore, the supplier is willing to work with the government, that is, the government has the right to decide the procurement mode.

Figure 6 compares the reserves of RGSR and RGEOR. It can be seen that under the option contract, Q_r^* is always smaller than $Q_\omega^{U}*$, but $Q_r^* + q_r^*$ is always bigger than $Q_\omega^{U}*$. For RGEOR, it can not only reduce the government material self-reserve but also increase the total reserve, which verifies the correctness of proposition 4. According to the characteristics of weak economy in the process of government reserve of emergency supplies, in order to ensure the ability of emergency support, the government should preferentially choose RGEOR.

6 Concluding Remarks

In this paper, RGEOR is proposed to deal with the risks of shortage and waste of emergency supplies in the process of emergency supplies reserve. Through relevant analysis, the following conclusions and management enlightenment are drawn:

(1) The paper deduces the condition that the rotation can increase the government reserve quantity in the separate government reserve mode. It shows that whether the government will adopt the rotation operation is related to the rotation cost of suppliers. If the rotation cost of suppliers is low, the government will choose RGSR; if the rotation cost is too high, the government will choose GSR.
(2) The paper analyzes the conditions for the establishment of RGEOR, and proves that on the premise of the establishment of RGEOR, it can not only increase the government's total reserves but also reduce the quantity of self-stored emergency materials, then the reserve pressure of government will reduce and the ability to guarantee the emergency supplies will enhance.
(3) The paper describes suppliers' profit under the three modes through numerical experiment, which proves that the supplier is profitable under RGEOR and the returns are higher than GSR and RGSR. Therefore, suppliers are willing to participate in RGEOR.

In this paper, we just simply describe the pricing decision of suppliers by numerical experiment. Supplier's pricing decision is an important part of the cooperation between government and enterprise, which is also worth studying in the future.

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