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DEALING WITH SUPPLY DISRUPTION RISKS: DUAL SOURCING OR SINGLE SOURCING WITH EMERGENCY OPTION

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Abstract. *In this paper, we study dual sourcing mode and single sourcing with emergency option mode in a decentralized supply chain to deal with supply disruption. Then we study how to choose between them through comparing the homogeneity and heterogeneity of wholesale price and supply reliability. It is shown: when the suppliers are homogeneous both in wholesale price and supply reliability, single sourcing with emergency option mode is better than dual sourcing mode, except in the following two special conditions: the wholesale price of the two is much lower compared with the option price and at the same time the dispersion degree of reliability is small enough, or the reliability of the two is both very high; when the two suppliers are heterogeneous in wholesale price, the optimal mode is turning from dual sourcing mode to single sourcing with emergency option mode as the heterogeneity rises; when the two are heterogeneous in supply reliability, the optimal mode is turning from single sourcing with emergency option mode to dual sourcing mode as the heterogenicity rises.*
Keywords: Supply disruption risks, Reliability, Dual sourcing, Emergency option

1. **Introduction.** Supply disruption does harm with financial loss and operation failure. For example, Ericsson lost 400 million euros after their supplier's semiconductor plant in New Mexico caught fire in 2000; Land Rover laid-off 1,400 workers after one of their key suppliers became insolvent in 2007. There are many ways to deal with supply disruption, including safety stock (Toyota, Sears), flexible supply (GM, Dell), make-and-buy (Zara, HP), postponement strategy (Xilinx, Benetton), and dual sourcing. Nowadays, more and more enterprises pay attention to financial strategy to deal with supply disruption risks, for example, buying emergency option. However, how to use emergency option mode accurately? And how to choose between dual sourcing mode and emergency option mode? These problems have never been involved in the existing studies, but urgently need to be resolved.

In dual sourcing mode, the buying firm can scatter the risks of supply disruption by sourcing from two suppliers whose supply reliability is not correlative. For example, the Chinese motor firm SAIC Motor usually procures the same product from two suppliers.

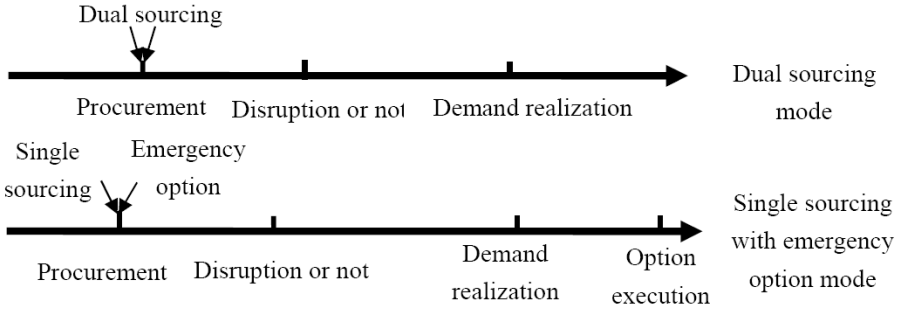


FIGURE 1. The chronological sequence of the events

From 2006 to now, they procured car glass from two suppliers, Fuyao and Yaopi. With this mode, the supply of glass never came across large trouble.

In single sourcing with emergency option mode, the buying firm procures products from a single unreliable supplier, and simultaneously purchases an option of buying up to a certain quantity from the supplier who guarantees the availability of the product. The buying firm needs to pay option reservation cost. When coming up against disruption, the buying firm can execute the option in a size needed, and simultaneously pay the option execution cost. In practice, many firms use this mode to deal with supply disruption risks. For example, the largest Chinese Hong Kong commercial company Li and Fung Company uses this mode to procure almost all product. They do this to minish their risks of supply disruption, because even a little dissatisfaction of their customers will bring them huge financial damages. The chronological sequence of the events is showed in Figure 1.

The related study of dual sourcing is very plentiful. Anupindi and Akella (1993) [1] concentrate on supply uncertainty and characterize several scenarios where single sourcing is preferable to dual sourcing in such a setting. Agrawal and Nahmias (1997) [2] analyze the supplier sourcing decision in the presence of yield uncertainty and deterministic demand when there are fixed costs associated with sourcing from each individual supplier. Ryu and Lee (2003) [3] consider dual-sourcing models with stochastic lead time and constant unit demand. Tomlin and Wang (2005) [4] connect the mix-flexibility and dual-sourcing supply-chain structures. Dada et al. (2007) [5] examine the newsvendor's procurement problem when suppliers are unreliable. Kouvelis and Li (2008) [6] consider replenishment decisions for a constant rate demand environment from a supplier with uncertain lead times. Liu et al. (2009) [7] investigate the value of higher reliability and examines a case in which a retailer pays a higher unit price for higher reliability. Wang et al. (2010) [8] explore a model in which a firm can source from multiple suppliers and/or exert effort to improve supplier reliability. Oberlaender (2011) [9] analyses dual sourcing strategies using an extended single-product newsvendor model with two order points, and shows that dual sourcing strategies are always preferable to an exclusive offshore approach.

Our paper is also related to the emergency option literatures. M. Khouja (1996) [10] solves a newsboy problem with an emergency supply option. Barnes-Schuster et al. (2002) [11] illustrate how options provide flexibility to a buyer to respond to market changes in the second period using a two-period model with correlated demand. Babich (2006) [12] presents valuation of inventory-reorder options in a competitive environment with defaultable suppliers and studies the value of the deferment option. Xu and Nozick (2009) [13] study the use of option contracts for global supply chain design. Xu (2010) [14] studies the situation that the manufacturer may purchase option contracts from the supplier before the demand is realized, or order after the demand is realized, which is subject to random pricing and uncertain availability. Y. Xia et al. (2010) [15] study two

contract mechanisms to share risks in a decentralized supply chain: the option contract and the firm order contract.

Compared with the existing literatures, the technical innovations of current work are as follows. First, about dual sourcing mode, compared with the existing studies (mainly Dada et al. (2007) [5]), this research is based on supply reliability following a general distribution rather than being completely reliable or unreliable (0-1 binomial distribution). Here, the use of the Hollder Inequality is a methodological innovation. This approach can assure our conclusions to be more general. Second, compared with the existing studies (mainly Y. Xia et al. (2010) [15]), this paper introduces the emergency option strategy into single sourcing mode. This is a strategical innovation.

Compared with the sourcing modes in the existing literatures, the single sourcing with emergency option mode can combine the cost advantage of single sourcing mode and the risk dispersion advantage of buying emergency option, and is of greater application value. This mode is particularly suitable for trade enterprises.

In this paper, we modeling the profit of the buying firm in the two modes respectively, prove the concavity of the models, and characterize the optimal procurement quantities and emergency option quantities. Then, we study how to choose between them through comparing the homogeneity and heterogeneity of wholesale price and supply reliability respectively.

2. **Model Description.** We consider the problem faced by a buying firm who provides a single kind of product over a single selling season. The demand w for the product is stochastic, and is characterized by distribution and density functions, $F(w)$ and $f(w)$, respectively. The firm can source from two suppliers $i = 1, 2$. Because of some emergence, the suppliers are unreliable in that the quantity delivered by supplier i is less than or equal to the order quantity (q_i). We define the supplier' delivered proportion after disruptions to be supply reliability, and let r_i denote it. Let $g_i(r_i)$ denote the continuous probability density function associated with r_i (r_i is ≤ 1) for each supplier i. We assume that this density function is twice differentiable and $\bar{r_i}$ and σ_i represent the mean and standard deviation, respectively. In line with prior research, we also assume that $\sigma_i \leq \bar{r_i}$ or that the coefficient of variation is ≤ 1. σ_i represents the dispersion degree of such kind of influence.

In dual sourcing mode, the wholesale price is c_i. We assume the selling price per unit (p), the unit salvage value (s) for unsold stock and unit underage cost (u) for unsatisfied demand are all known. $p > c_i > s$ is assumed to hold for our analysis.

In single sourcing with emergency option mode, the whole price of option is c_o, which is divided into two parts, the reservation price (αc_o) and the execution price ($(1-\alpha)c_o$). The firm should pay $\alpha c_o$for unit option when purchasing the right of get a reliable supply no more than a limited mount, and pay the rest ($(1-\alpha)c_o$) when executing the option. Here, we assume $(1-\alpha)c_o > s$, otherwise, the buying firm will execute all the option to the limit to get a higher profit. We also assume $c_o \geq c_1$. c_1 is the minimum of all c_i. The reservation quantity of option is M, and the execution quantity is m. Here, M must be $\geq m$. Besides, the profit of the buying firm is π.

3. **Dual Sourcing Mode.** According to the study by G. J. Burke et al. (2007) [16], the buying firm should choose the cheapest N suppliers to build multiply sourcing mode. In this paper, we let the cheapest two suppliers to be supplier 1 and supplier 2. The wholesale price of the cheapest one is c_1, and the wholesale price of another one is c_2 ($c_1 < c_2$). We assume $\bar{r_1} < \bar{r_2}$. The objective function given below in Equation (1) maximizes the single

period expected profit $E(\pi)$ for the buying firm.

$$
\begin{aligned}
&MaxE(\pi)\\
&= \int_0^1 g_1(r_1) \int_0^1 g_2(r_2) \Bigg[\int_0^{r_1q_1+r_2q_2} (pw - (r_1q_1c_1 + r_2q_2c_2) + s(r_1q_1 + r_2q_2 - w))\, f(w)dw\\
&\quad + \int_{r_1q_1+r_2q_2}^{\infty} (pw - (r_1q_1c_1 + r_2q_2c_2) - u(w - r_1q_1 - r_2q_2))\, f(w)dw \Bigg] dr_2dr_1
\end{aligned} \tag{1}
$$

$$\text{subject to: } q_i \geq 0,\ \forall i \tag{2}$$

With the above equations, we can get Lemma 3.1.

Lemma 3.1. *The expected profit function shown in Equation (1) is concave in the order quantities q_i.*

Proof: $\frac{\partial E(\pi)}{\partial q_1} = \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[(p - c_1 + u)r_1 - (p - s + u)r_1F(r_1q_1 + r_2q_2)]dr_1dr_2$, $\frac{\partial E(\pi)}{\partial q_2} = \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[(p - c_2 + u)r_2 - (p - s + u)r_2F(r_1q_1 + r_2q_2)]dr_1dr_2$.

Then, $\frac{\partial^2 E(\pi)}{\partial q_1^2} = \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[-(p - s + u)r_1^2F(r_1q_1 + r_2q_2)]dr_1dr_2 < 0$, $\frac{\partial^2 E(\pi)}{\partial q_2^2} = \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[-(p - s + u)r_2^2F(r_1q_1 + r_2q_2)]dr_1dr_2 < 0$.

Given 2 suppliers, the Hessian is:

$$
H_2 = \begin{vmatrix} \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[-(p - s + u)r_1^2F(r_1q_1 + r_2q_2)] dr_1dr_2 & \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[-(p - s + u)r_1r_2F(r_1q_1 + r_2q_2)] dr_2dr_1 \\ \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[-(p - s + u)r_1r_2F(r_1q_1 + r_2q_2)] dr_2dr_1 & \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[-(p - s + u)r_2^2F(r_1q_1 + r_2q_2)] dr_1dr_2 \end{vmatrix}
$$

We introduce the Hollder Inequation, which is $\int fgdx \leq (\int |f|^p\, dx)^{\frac{1}{p}} (|q|^q\, dx)^{\frac{1}{q}}$.

$p + q = 1$, and when $f = g$, the inequation turns to be equation. We can obtain that,

$$
\begin{aligned}
H_2 = (p - s + u)^2 \Bigg\{ &\Bigg\{ \Bigg\{ \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[r_1^2F(r_1q_1 + r_2q_2)]dr_2dr_1 \Bigg\}^{\frac{1}{2}}\\
&\Bigg\{ \int_0^1 g_1(r_1) \int_0^1 g_2(r_2)[r_2^2F(r_1q_1 + r_2q_2)]dr_2dr_1 \Bigg\}^{\frac{1}{2}} \Bigg\}^2\\
&- \Bigg\{ \int_0^1 g_1(r_1) \int_0^1 g_2(r_2) \left[r_1\sqrt{F(r_1q_1 + r_2q_2)} r_2\sqrt{F(r_1q_1 + r_2q_2)} \right] \Bigg\}^2 \Bigg\}
\end{aligned}
$$

Here, $\bar{r}_1 \neq \bar{r}_2$, so, $H_2 > 0$.

We can obtain that Equation (1) is concave in the order quantities q_i.

We assume demand to be uniformly distributed with parameters $[a, b]$ to get the optimal q_i. The following conditions are necessary and sufficient to identify a global optimum to our sourcing problem:

$$\frac{\partial E(\pi)}{\partial q_i} \leq 0,\ \forall i; \quad q_i \geq 0,\ \forall i; \quad q_i \left[\frac{\partial E(\pi)}{\partial q_i} \right] = 0,\ \forall i. \tag{3}$$

Theorem 3.1. *Assume demand to be uniformly distributed with parameters $[a, b]$, the optimal quantity sourced from each supplier i is as follows:*

$$
q_1^* = \frac{\frac{\bar{r}_1}{\sigma_1^2} \left[\frac{(c_2 - c_1)(b - a)}{p - s + u} \frac{\bar{r}_2^2}{\sigma_2^2} + \frac{(c_1 - s)a + (p - c_1 + u)b}{p - s + u} \right]}{\frac{\bar{r}_1^2}{\sigma_1^2} + \frac{\bar{r}_2^2}{\sigma_2^2} + 1}, \tag{4}
$$

$$q_2^* = \frac{\frac{\bar{r}_2}{\sigma_2^2}\left[\frac{(c_1-c_2)(b-a)}{p-s+u}\frac{\bar{r}_1^2}{\sigma_1^2} + \frac{(c_2-s)a+(p-c_2+u)b}{p-s+u}\right]}{\frac{\bar{r}_1^2}{\sigma_1^2} + \frac{\bar{r}_2^2}{\sigma_2^2} + 1}. \tag{5}$$

Proof: We know that Equation (1) is concave in the decision variables. Now assuming that $q_i^* > 0$, we know that through the complementary slackness condition:

$$\frac{\partial E(\pi)}{\partial q_1} = \int_0^1 g_1(r_1)\int_0^1 g_2(r_2)[(p-c_1+u)r_1 - (p-s+u)r_1F(r_1q_1+r_2q_2)]dr_1dr_2 = 0, \text{ and}$$

$$\frac{\partial E(\pi)}{\partial q_2} = \int_0^1 g_1(r_1)\int_0^1 g_2(r_2)[(p-c_2+u)r_2 - (p-s+u)r_2F(r_1q_1+r_2q_2)]dr_1dr_2 = 0,$$

We can obtain the result in Equations (4) and (5).

From Theorem 3.1, we can get some conclusions.

First, we can get the conclusion that it is the wholesale price who determines the supplier selection. That is because: from Equations (4) and (5), for $c_2 > c_1$, when $q_2^* \geq 0$, then $\frac{(c_2-s)a+(p-c_2+u)b}{p-s+u}$ must be ≥ 0, so $\frac{(c_1-s)a+(p-c_1+u)b}{p-s+u} \geq 0$, we can obtain that q_1^* must be ≥ 0; however, when $q_1^* \geq 0$, we cannot get $q_2^* \geq 0$.

Second, we can also get the conditions when the single sourcing is the optimal mode, which is shown in Corollary 3.1.

Corollary 3.1. *The single sourcing mode is better compared to dual sourcing mode when:*

$$\left(\frac{\sigma_1}{\bar{r}_1}\right)^2 \leq \frac{(c_2-c_1)(b-a)}{b(p-c_2+u)+a(c_2-s)}. \tag{6}$$

When using single sourcing mode, the cheaper supplier should be chosen to order.

When the squared coefficient of variation of the cheaper supplier is small in comparison with reliability, the supplier should be chosen to receive the overall order.

4. **Single Sourcing with Emergency Option Mode.** After the demand becomes realized, the vacancy between the delivery quantity from the unreliably supplier and demand also becomes known. Let us start by expressing the profit function of the buying firm in this mode as:

$$\pi = \begin{cases} pw - r_1q_1c_1 + s(r_1q_1 - w) - \alpha c_oM, & \text{if } w \leq r_1q_1 \\ pw - r_1q_1c_1 - (1-\alpha)c_o(w - r_1q_1) - \alpha c_oM, & \text{if } r_1q_1 < w \leq r_1q_1 + M \\ p(r_1q_1 + w) - r_1q_1c_1 - (1-\alpha)c_oM - u(w - r_1q_1 - M) - \alpha c_oM, & \text{if } w > r_1q_1 + M \end{cases} \tag{7}$$

Based on Equation (7), the objective function given below maximizes the single period expected profit $E(\pi)$ for the buying firm.

$$\begin{aligned} MaxE(\pi) = \int_0^1 g_1(r_1)\Big\{ &\int_0^{r_1q_1}[pw - r_1q_1c_1 + s(r_1q_1 - w)]f(w)dw \\ &+ \int_{r_1q_1}^{r_1q_1+M}[pw - r_1q_1c_1 - (1-\alpha)c_o(w - r_1q_1)]f(w)dw \end{aligned}$$

$$+\int_{r_1q_1+M}^{\infty}[p(r_1q_1+w)-r_1q_1c_1-(1-\alpha)c_oM \\ -u(w-r_1q_1-M)]f(w)dw\Big\}dr_1-\alpha c_oM \tag{8}$$

subject to: $q_1, M \geq 0$ (9)

With the above equations, we can get Lemma 4.1.

Lemma 4.1. *The expected profit function shown in Equation (8) is concave in the order quantities q_1 and the option reservation quantity M.*

Proof: $\frac{\partial E(\pi)}{\partial q_1}=(p-c_1+u)\int_0^1 r_1g_1(r_1)dr_1-\int_0^1\{[p-(1-\alpha)c_o+u]F(r_1q_1+M)+[(1-\alpha)c_o-s]F(r_1q_1)\}r_1g_1(r_1)dr_1$, $\frac{\partial E(\pi)}{\partial M}=(p-c_o+u)-[p-(1-\alpha)c_o+u]\int_0^1 F(r_1q_1+M)g_1(r_1)dr_1$.

Then, $\frac{\partial^2 E(\pi)}{\partial q_1^2}=-\int_0^1\{[p-(1-\alpha)c_o+u]f(r_1q_1+M)+[(1-\alpha)c_o-s]f(r_1q_1)\}r_1^2g_1(r_1)dr_1<0$, $\frac{\partial^2 E(\pi)}{\partial M^2}=-[p-(1-\alpha)c_o+u]\int_0^1 f(r_1q_1+M)g_1(r_1)dr_1<0$.

The Hessian is:

$$H_2 = \begin{vmatrix} -\int_0^1\begin{Bmatrix}[p-(1-\alpha)c_o+u]f(r_1q_1+M)\\+[(1-\alpha)c_o-s]f(r_1q_1)\end{Bmatrix}r_1^2g_1(r_1)dr_1 & -[p-(1-\alpha)c_o+u]\int_0^1 f(r_1q_1+M)r_1g_1(r_1)dr \\ -[p-(1-\alpha)c_o+u]\int_0^1 f(r_1q_1+M)r_1g_1(r_1)dr & -[p-(1-\alpha)c_o+u]\int_0^1 f(r_1q_1+M)g_1(r_1)dr \end{vmatrix}$$

Using the Hollder Inequation, we prove $H_2>0$. We can obtain that Equation (8) is concave in the order quantities q_1 and M.

Given that we have shown that our objective function is concave, we assume demand to be uniformly distributed with $[a,b]$ to get the optimal q_1 and M.

Theorem 4.1. *Assume demand to be uniformly distributed with parameters $[a,b]$, the optimal quantity sourced from supplier 1 and the optimal option reservation quantity is as follows:*

$$q_1^*=\frac{(c_1-\alpha c_o-s)\bar{r}_1a+(c_o-c_1)\bar{r}_1b}{[(1-\alpha)c_o-s]\bar{r}_1^2+(p-s+u)\sigma_1^2}, \tag{10}$$

$$M^*=\frac{(p-s+u)[\alpha c_oa+(p-c_o+u)b]\left(\bar{r}_1^2+\sigma_1^2\right)-[p-(1-\alpha)c_o+u][(c_1-s)a+(p-c_1+u)b]\bar{r}_1^2}{[p-(1-\alpha)c_o+u]\left[(p-s+u)\left(\bar{r}_1^2+\sigma_1^2\right)-(p-(1-\alpha)c_o+u)\bar{r}_1^2\right]} \tag{11}$$

Proof: Equation (8) is concave in the decision variables. Now assuming that q_1^*, $M^*>0$, we know that through the complementary slackness condition: $\frac{\partial E(\pi)}{\partial q_1}=(p-c_1+u)\int_0^1 r_1g_1(r_1)dr_1-\int_0^1\{[p-(1-\alpha)c_o+u]F(r_1q_1+M)+[(1-\alpha)c_o-s]F(r_1q_1)\}r_1g_1(r_1)dr_1=0$ and $\frac{\partial E(\pi)}{\partial M}=(p-c_o+u)-[p-(1-\alpha)c_o+u]\int_0^1 F(r_1q_1+M)g_1(r_1)dr_1=0$.

We can obtain the result in Equations (10) and (11).

From Equation (10), we can also get Corollary 4.1 and Corollary 4.2.

Corollary 4.1. *The single sourcing mode is better compared with single sourcing with emergency option mode when:*

$$\frac{\bar{r}_1^2+\sigma_1^2}{\bar{r}_1^2}\leq\frac{[p-(1-\alpha)c_o+u][(c_1-s)a+(p-c_1+u)b]}{(p-s+u)[\alpha c_oa+(p-c_o+u)b]} \tag{12}$$

When the squared coefficient of variation of the cheapest supplier is very small, then the cheapest supplier will receive the overall order, and the buying firm should abandon the approach of purchasing emergency option.

Corollary 4.2. *The optimal quantity q_1^* is always positive, that is to say, the buying firm must order from the reliable supplier when using the single sourcing with emergency option mode, no matter whether to purchase option or not.*

Proof: From Equation (10), we have

$$(c_1 - \alpha c_o - s)\bar{r}_1 a + (c_o - c_1)\bar{r}_1 b = [(c_o - c_1)b + (c_1 - \alpha c_o)a - sa]\,\bar{r_1}$$
$$\geq [(c_o - c_1)a + (c_1 - \alpha c_o)a - sa]\,\bar{r_1} = [(1-\alpha)c_o - s]a\,\bar{r_1}$$

(For $c_o \geq c_1$). Because $(1-\alpha)c_o > s$, $\bar{r_1} > 0$. We can get $(c_1-\alpha c_o-s)\bar{r}_1 a+(c_o-c_1)\bar{r}_1 b > 0$. So $q_1^* = \frac{(c_1-\alpha c_o-s)\bar{r}_1 a+(c_o-c_1)\bar{r}_1 b}{[(1-\alpha)c_o-s]\bar{r}_1^2+(p-s+u)\sigma_1^2} > 0$.

From Corollary 4.2, we can obtain that the buying firm may abandon the purchase of emergency option, but he should never abandon the order from the single supplier except when the reliability of the supplier drops to be zero ($\bar{r_1} = 0$). The main reason may be the lower wholesale price of supplier 1 compared with emergency option. And the supplier can at least deliver a small amount of products with a lower wholesale price even when the supply reliability is low enough after an emergence or some production fault. So the buying firm must order from the reliable supplier when using the single sourcing and emergency option mode, even though $c_o = c_1$.

Through analysis, we can obtain other conclusions.

First, in single sourcing with option mode, the optimal order quantity from supplier 1 (q_1^*) decreases with the wholesale price of supplier 1 (c_1); and the optimal option reservation quantity (M^*) increases with the wholesale price of supplier 1 (c_1).

Second, we can obtain that Equation (10) is a decreasing function of σ_1^2, and Equation (11) is a increasing function of σ_1^2. That is to say, as the dispersion degree of the influence to supply by emergency and operation faults becomes larger, the optimal order quantity from the supplier decreases, and the optimal option reservation quantity increases. As the influence of supply reliability to the optimal order quantity and option quantity, we carry out a numerical study to investigate this problem. We set $p = 1.2$, $s = 0.1$, $u = 0.1$, $a = 20$, $b = 120$, and set $c_o = 1$, $c_1 = 0.6$, $\sigma_1^2 = 0.06$, $\alpha = 0.5$, and $\bar{r_1} = 0$ to 1 in increments of 0.1. Through computer operations, we obtain the following figure.

From Figure 2, we can obtain that, the optimal option reservation quantity decreases with the reliability of the supplier. And as the reliability of the supplier increases, the optimal order quantity from it increases at first, and then decreases. The reason may be that a high supply reliability of the supplier can reduce the disruption risks. When the reliability is high enough, the optimal sourcing mode turns to be single sourcing. However, as the reliability continues to rise, the buying firm should begin to reduce the order quantity from the supplier constantly. That is because, at this moment, the disruption risks of the buying firm become smaller, and there is no need for the firm to order a quantity larger than demand.

5. **Comparison.** We divide the suppliers by two kinds: homogeneous suppliers and heterogeneous suppliers. The former are suppliers of which the wholesale price and the supply reliability are both similar. The buying firm can source from two homogeneous suppliers or source from the cheaper supplier singly and reserve emergency option. The later are suppliers of different wholesale price or reliability. The buying firm can source from two

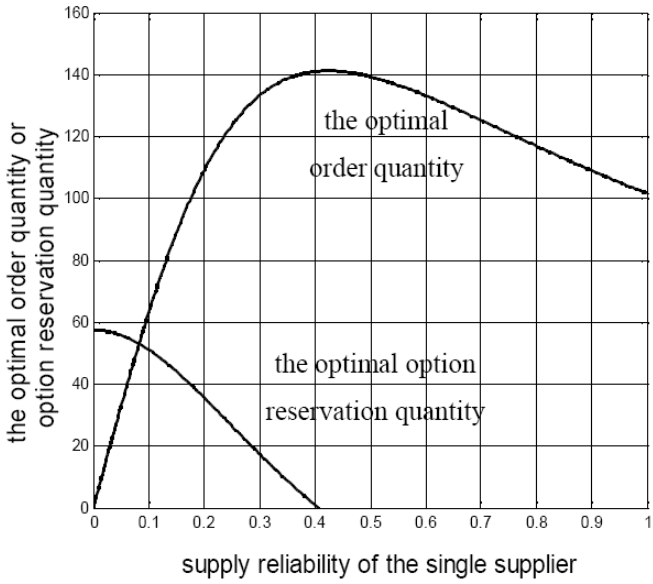


FIGURE 2. Influence of reliability to the order quantity and option reservation quantity

heterogeneous suppliers or source from the cheaper supplier singly and reserve emergency option. We study how the firm chooses the mode when faced with two homogeneous suppliers or heterogeneous suppliers.

5.1. **Homogeneous suppliers.** We define $\Delta c = c_2 - c_1$ and $\Delta \bar{r} = \bar{r}_2 - \bar{r}_1$, then the two suppliers can be called homogeneous suppliers as Δc or $\Delta \bar{r}$ drops to zero.

Firstly, we set $p = 1.2$, $s = 0.1$, $u = 0.1$, $a = 20$, $b = 120$, $c_o = 1$, $\bar{r_1} = \bar{r_2} = 0.8$, $\alpha = 0.5$. We set two cases, $\sigma_1^2 = \sigma_2^2 = 0.06$ and $\sigma_1^2 = 0.06$, $\sigma_2^2 = 0.12$ respectively, and let $c_1 = c_2 = 0.1$ to 1. Based on Equations (2), (4), (5), (8), (10) and (11), we compute the profit of the buying firm, and get Figures 3(a) and 3(b). Then, we set $c_o = 1$, $c_1 = c_2 = 0.6$, $\sigma_1^2 = \sigma_2^2 = 0.06$, $\alpha = 0.5$, and let $\bar{r_1} = \bar{r_2} = 0$ to 1, and get Figure 3.

When the two suppliers are homogeneous, the optimal profit of the buying firm using single sourcing with emergency option mode is higher than the optimal profit of the buying firm using dual sourcing mode, except in the following condition: the wholesale price of the two suppliers is both very low and at the same time the dispersion degree of reliability is small enough when homogeneous in wholesale price, or the reliability of the two suppliers are both very high when homogeneous in supply reliability. The reason may be as follows. Although the supplier's reliability is much lower than the option's, the buying firm can forecast it more accurately when the dispersion degree is small. And if the wholesale price of the supplier is low enough at the same time, the buying firm can get a higher profit using dual sourcing mode than purchasing option. However, with a wholesale price lower than option price, dual sourcing from two suppliers of high reliability can bring a higher profit than single sourcing with emergency option.

5.2. **Heterogeneous suppliers.** The two suppliers can be called heterogeneous suppliers as Δc or $\Delta \bar{r}$ significantly greater than zero. Here, we study how the buying firm should make a choice between dual sourcing mode of two heterogeneous suppliers and single sourcing with emergency option mode.

Firstly, we set $p = 1.2$, $s = 0.1$, $u = 0.1$, $a = 20$, $b = 120$, $c_o = 1, \bar{r_1} = \bar{r_2} = 0.8$, $\sigma_1^2 = \sigma_2^2 = 0.06$, $\alpha = 0.5$, let $c_1 = 0.1$, and study the influence of variation of Δc from 0 to

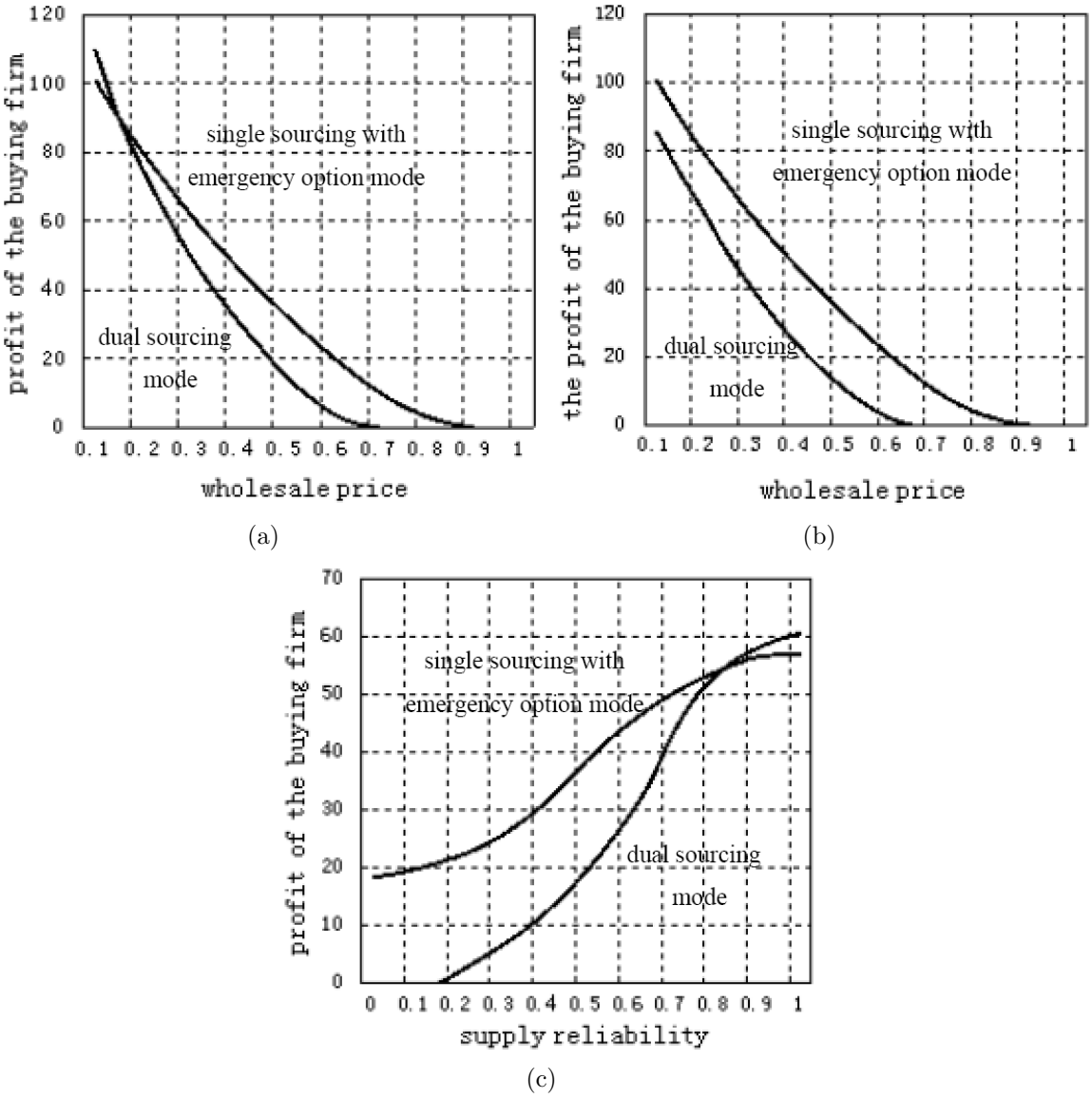
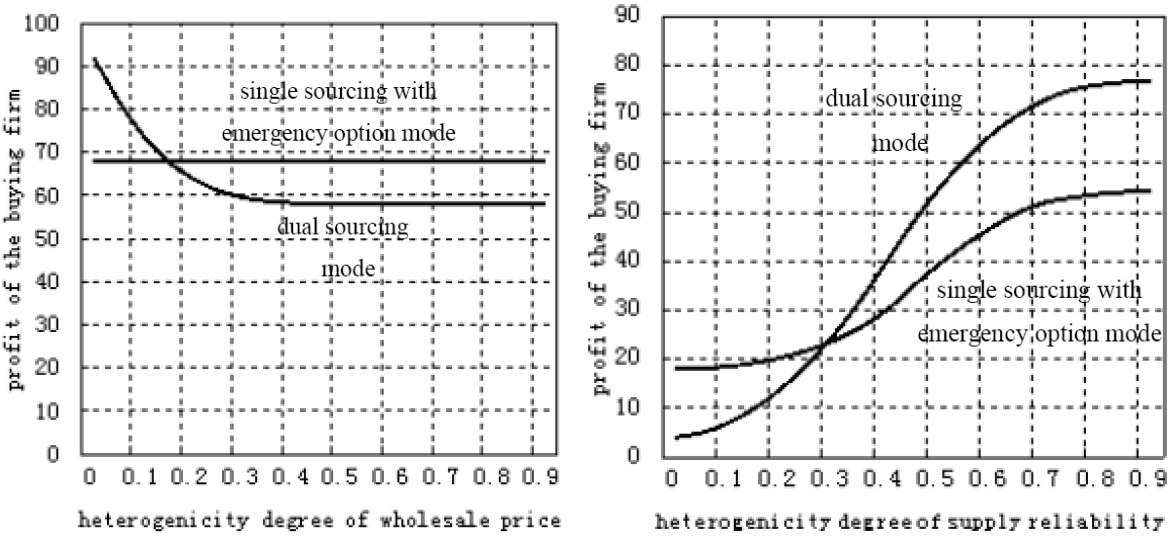


FIGURE 3. The buying firm's choice when faced with homogeneous suppliers

0.9 on the choice (see Figure 4(a)). Then, we set $c_o = 1$, $c_1 = c_2 = 0.6$, $\sigma_1^2 = \sigma_2^2 = 0.06$, $\alpha = 0.5$, let $\bar{r}_2 = 0.1$, and study the influence of variation of $\Delta\bar{r}$ from 0 to 0.9 on the choice (see Figure 4(b)).

Seeing from Figure 4, we can obtain such conclusions: when the two suppliers are heterogeneous in wholesale price, the optimal mode is turning from dual sourcing mode to single sourcing with emergency option mode as the heterogeneity increases; when the two suppliers are heterogeneous in supply reliability, the optimal mode is turning from single sourcing with emergency option mode to dual sourcing mode as the heterogenicity increases. The main reason is as following: when supply risks have not been effectively dispersed, dual sourcing from two suppliers of high heterogeneity can not bring reduction of procurement costs, so the emergency option mode is better; when the heterogeneity degree of supply reliability is low, another supplier of reliability not high cannot disperse risks, so purchasing emergency option is superior to dual sourcing; however, when the heterogeneity degree of supply reliability is high, another supplier of higher wholesale



(a) (b)

FIGURE 4. The buying firm's choice when faced with heterogeneous suppliers

price, which is of high reliability simultaneously, can effectively disperses the risks. In this condition, dual sourcing is appropriate.

Seeing from Figures 3(c) and 4(b), we can also obtain that the buying firm's profit using single sourcing with emergency option mode is steadier than using dual sourcing mode, no matter homogeneous or heterogeneous suppliers. If the firm is of risk aversion, purchasing emergency option is better to deal with supply disruption.

6. **Conclusions.** In this paper, we analyze single period, single product sourcing decisions under supply disruption risks and demand uncertainty. We study two sourcing modes about dealing with supply disruption risks in a decentralized supply chain. Then, we compare the two modes, and study how to choose between them.

We can obtain some conclusions: when the suppliers are homogeneous both in wholesale price and supply reliability, single sourcing with option mode is better than dual sourcing mode, except in the following two special conditions: the wholesale price of the two suppliers is much lower compared to the option price and at the same time the dispersion degree of reliability is small enough, or the reliability of the two suppliers are both very high; when the two suppliers are heterogeneous in wholesale price, the optimal mode is turning from dual sourcing mode to single sourcing with emergency option mode as the heterogeneity increases; when the two suppliers are heterogeneous in supply reliability, the optimal mode is turning from single sourcing with emergency option mode to dual sourcing mode as the heterogenicity increases.

Our results imply that if there are several suppliers who have similar wholesale price and supply reliability, for example, suppliers of similar scale and short geographic distance between each other, the buying firm should source from the single supplier of the lowest wholesales price, and simultaneously buy the emergency option to disperse risks. This is of great significance in the supply chain designing of trade enterprises and the sourcing strategy designing of manufacturers' particular raw materials, for example, rare earth. However, for the majority of manufacturers, if there are several suppliers of long geographical distance between each other, or of very different scale, dual sourcing is a better choice, for example, electronic equipment manufacturers and automobile manufacturers.

Future researches will include the combined mode and the subdivision of option execution. We want to know whether a mode combining the two modes is better dealing with supply disruption and how to build it. Besides, if the option execution is before the demand being known, how does the buying firm choose the optimal mode?

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