International Journal of Innovative Computing, Information and Control
Volume **8**, Number **8**, August **2012**

ICIC International ©2012 ISSN 1349-4198
pp. 5775–5785

THE IMPACT OF DEMAND UNCERTAINTY ON DECISIONS OF SOURCING STRATEGIES UNDER SUPPLY DISRUPTION RISKS

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Received March 2011; revised August 2011

Abstract. *This paper investigates the impacts of both the demand uncertainty and the supply disruption probability on the decisions of two sourcing strategies: one is dual sourcing and the other is single sourcing with contingent supply. The expected profit functions and the optimal decisions of the buyer are derived and compared. Then sensitivity analysis is given through numerical examples. Explicit insights are given into how (a) the buyer's order quantity decisions under both sourcing strategies are affected by the variability in demand; (b) demand uncertainty moderates the effects of the wholesale prices; and (c) the buyer's expected profit changes with the demand uncertainty under different supply disruption frequencies.*

Keywords: Sourcing strategy, Demand uncertainty, Supply disruption, Order quantity decisions

1. **Introduction.** The literature never lacks of researches on risk management (for example, Li and Gao [1]). There are two main supply chain risks: one is supply chain disruptions, and the other is normal demand-supply coordination risks [2]. And with more attention given to the former risks recently, especially after the 9-11 terrorist attacks, a large quantity of researches focus on exploring effective sourcing strategies to deal with supply disruptions. In various industries, backup supply has been proved to be one of the efficient ways for the buyers to mitigate unexpected risks. There are usually two backup sourcing strategies: contingent sourcing – whereby you source from an alternative supplier in the event of a failure at your primary supplier; and dual sourcing – whereby you simultaneously source from two suppliers [2]. Companies have to balance the pros and cons of both strategies and then select one sourcing strategy to deal with supply disruptions and demand uncertainties.

For example, during the fire disruption in 2000 that shut down the Philips Semiconductor plant, Nokia was able to temporarily increase production at alternative suppliers and suffered little financial impact, whereas Ericsson used single-source strategy and had lost over $400 million in potential revenue [3]; HP has used "dual response manufacturing" to supply inkjet printers: a Vancouver, WA supplier to launch new products and deal with demand peaks, and a low cost supplier in Singapore to handle most of the production [4]; after the Japan earthquake in Mach 2011, Renesas Electronics – the world's largest manufacturer of semiconductors for automobiles – commissioned plants owned by Global Foundries, a US semiconductor company, and TSMC, a Taiwanese company, to replace some global supply of semiconductors for automobiles and mobile phones [5]. All these practical examples have shown the importance of selecting the right sourcing strategies when facing supply disruptions. While making such sourcing decisions, demand uncertainty is often ignored, which would result in high demand-supply coordination risks. If the actual demand is lower or larger than the backup supply's capability, there may be large under-cost or overstock cost for the retailer, thus in turn weakening the effectiveness of the chosen strategy. Therefore, demand risks should be taken into account when supply-continuity tactics are evaluated [6].

Our paper tries to examine the impacts of demand uncertainty under two common strategies: using a contingent supply and dual sourcing. As will be discussed in the following literature review, the problem studied in this paper has not been fully addressed in the literature. It is intuitive that "Emergency (contingent) sourcing becomes less attractive as demand risk grows, while dual sourcing actually becomes more attractive as demand risk grows [2]." We attempt to figure out how exactly the demand uncertainty could affect the buyer's order quantity decisions and thereby his/her expected profits under two sourcing strategies. Specifically, the profit function of the retailer is first obtained, and then the optimal decisions are derived for each sourcing method. Finally, the effects of the demand uncertainty, represented by its standard deviation, are examined both analytically and numerically.

The impacts of demand uncertainty in supply chain context has been the subject of many researches (for example, Tominaga et al. [7]), while most of which assumed that no disruption occurs, that is, the supply is continuous. Mantrala and Raman [8] investigated how the demand uncertainty affects the return policies between a supplier and a retailer with two or more store outlets with normally distributed and possibly correlated demands. Hua et al. [9] studied the impacts of retail demand uncertainty on wholesale price, order quantity and retail price, and found that the cooperation between the manufacture and the retailer can only be implemented if the fluctuation of retail-market demand is relatively small. In the most recent study, Xu et al. [10] focused on the effects of demand uncertainty on optimal decisions and the expected profit of a price-setting newsvendor who faces either additive or multiplicative stochastic demand. Cao et al. [11] examined the distribution channel choice of competing manufacturers under demand uncertainty and resale price maintenance. Our paper differs from the above literature in that we incorporate two risks into sourcing decisions simultaneously: supply disruption and demand uncertainty. And the impacts of demand uncertainty interacting with different disruption frequencies are studied.

Contingent sourcing [12,13] and dual sourcing [14,15] have been studied extensively in the field of supply chain risk management. Since supply chains have complex structures and various external environments, we have noticed that the literature on the two sourcing strategies is characterized by different impact factors or constraints, for example, disruption frequency [16], backup contract parameters [17,18], supplier capacity limitations [19], lead-time [20], and dual-sourcing policies [21]. Although a large body of studies was conducted under stochastic demand, how the buyer's order decisions and profit could be affected by the variability in demand has not been concerned and compared under contingent sourcing and dual sourcing strategies. In this paper, we aim to identify such impacts and provide guidelines for how to use each sourcing method and measure various risk environments.

The remainder of the paper is organized as follows. Section 2 presents the expected profit functions and order decisions under two sourcing strategies in the presence of supply disruption risks. The impacts of demand uncertainties are then analyzed assuming the demand follows a normal distribution in Section 3. A set of numerical analysis is given to obtain more insights in Section 4. Finally, Section 5 concludes our paper and provides some possible future research directions.

2. Model Development.

2.1. Model assumptions and notation.

The retailer faces a random demand (X) in each cycle, and she could order from two suppliers once before the actual demand is realized because of the long lead-time. Supplier 1 is prone to supply disruptions but provides lower wholesale price. Supplier 2 is reliable while offering larger price. There are two kinds of sourcing strategies for the retailer: single sourcing from supplier 1 with contingent sourcing from supplier 2, and dual sourcing. We assume the demand uncertainty has different effects for the buyer under two sourcing methods, and try to investigate such differences in the following analysis. The notations used in the model are listed as:

y_i	order quantity to supplier i ($i = 1, 2$ indexed the two suppliers);
q	disruption probability of supplier 1;
p	retailer's unit selling price;
X	random demand in units;
$F(X)$	cumulative density function (CDF) of X, with $f(X)$ as the probability density function (PDF);
σ	standard deviation of the demand;
c_u	unit under-stock cost incurred at the retailer;
s	unit salvage price;
w_1	unit wholesale price of supplier 1;
w_2	unit wholesale price of supplier 2 under contingent sourcing;
w_3	unit wholesale price of supplier 2 under dual sourcing ($w_2 > w_3$);
r	unit transaction cost when placing orders incurred at the retailer.

Based on the above notations, the classical "newsboy problem" under two sourcing strategies are first summarized below.

2.2. The retailer's problem and solution under single sourcing with contingent supply.

Under single sourcing with contingent supply, the retailer orders from supplier 1 at the beginning of each cycle, and only when supplier 1 breaks down, does she order from supplier 2. Therefore, it is clear that the decisions of the order quantities from both suppliers are independent with each other. Like previous researchers, we derive the retailer's expected profit and then its optimal decisions.

The retailer's expected revenues are

$$R_1 = (1-q)p\left[\int_0^{y_1} xf(x)dx + \int_{y_1}^{\infty} y_1 f(x)dx\right] + qp\left[\int_0^{y_2} xf(x)dx + \int_{y_2}^{\infty} y_2 f(x)dx\right], \tag{1}$$

where the first item represents expected revenues when sourcing from supplier 1, and the second item is the expected revenues when disruption occurs and sourcing from the contingent supplier.

Next, the expected revenues from selling the products to a secondary market are

$$R_{s1} = (1-q)s\int_0^{y_1} (y_1 - x)f(x)dx + qs\int_0^{y_2} (y_2 - x)f(x)dx. \tag{2}$$

The total purchase cost is

$$C_1 = (1-q)w_1 y_1 + ry_1 + q(w_2 + r)y_2. \tag{3}$$

Finally, the total expected under-stocking cost is

$$C_{u1} = (1-q)c_u \int_{y_1}^{\infty} (x-y_1)f(x)dx + qc_u \int_{y_2}^{\infty} (x-y_2)f(x)dx. \tag{4}$$

The retailer's problem is to choose y_i so as to maximize her expected profits given by

$$\Pi_1 = R_1 + R_{s1} - C_1 - C_{u1}. \tag{5}$$

Thus, the first-order conditions (FOC) and the second order conditions (SOC) for optimal y_i derived from Π_1 are

$$FOC(y_1) = -r + (1-q)(p+c_u-w_1) - (1-q)(p+c_u-s)F(y_1), \tag{6}$$
$$FOC(y_2) = q\left[p+c_u-w_2-r-(p+c_u-s)F(y_2)\right]; \tag{7}$$
$$SOC(y_1) = -(1-q)(p+c_u-s)f(y_1) \le 0, \tag{8}$$
$$SOC(y_2) = -q(p+c_u-s)f(y_2) \le 0. \tag{9}$$

Therefore, if F^{-1} exists, we obtain

$$y_1^* = F^{-1}\left(\frac{(1-q_1)(p+c_u-w_1)-r}{(1-q_1)(c_u+p-s)}\right), \tag{10}$$
$$y_2^* = F^{-1}\left(\frac{p+c_u-w_2-r}{c_u+p-s}\right). \tag{11}$$

It is easy to find that if $(p+c_u-w_2-r) > 0$ holds, it is always valuable to use an available contingent supplier if the main supplier breaks down. However, from Equation (10), we can derive that, if the main supplier's disruption probability is larger than a certain value as below, the retailer may not order from this supplier, but directly use a reliable supplier 2:

$$q \ge q_1 = (p+c_u-w_1-r)/(p+c_u-w_1). \tag{12}$$

2.3. **The retailer's problem and solution under dual sourcing.** Under dual sourcing, the retailer orders from both suppliers simultaneously at the beginning of each cycle. Her expected revenues are

$$R_2 = (1-q)p\left[\int_0^{y_1+y_2} xf(x)dx + \int_{y_1+y_2}^{\infty} (y_1+y_2)f(x)dx\right] + qp\left[\int_0^{y_2} xf(x)dx + \int_{y_2}^{\infty} y_2 f(x)dx\right], \tag{13}$$

and the expected revenues from selling the products to a secondary market are

$$R_{s2} = (1-q)s \int_0^{y_1+y_2} (y_1+y_2-x)f(x)dx + qs \int_0^{y_2} (y_2-x)f(x)dx. \tag{14}$$

The total purchase cost is

$$C_2 = (1-q)w_1y_1 + w_3y_2 + r(y_1+y_2). \tag{15}$$

Finally, the total expected under-stocking cost is

$$C_{u2} = (1-q)c_u \int_{y_1+y_2}^{\infty} (x-y_1-y_2)f(x)dx + qc_u \int_{y_2}^{\infty} (x-y_2)f(x)dx. \tag{16}$$

The retailer's problem is to choose y_i so as to maximize her expected profits given by

$$\Pi_2 = R_2 + R_{s2} - C_2 - C_{u2}. \tag{17}$$

Similarly, we get that Π_2 is also concave related to y_i because

$$FOC(y_1) = -r + (1-q)(p+c_u-w_1) - (1-q)(p+c_u-s)F(y_1+y_2), \quad (18)$$

$$FOC(y_2) = p + c_u - w_3 - r - (1-q)(p+c_u-s)F(y_1+y_2) - q(p+c_u-s)F(y_2); \quad (19)$$

$$SOC(y_1) = -(1-q)(p+c_u-s)f(y_1+y_2) \leq 0, \quad (20)$$

$$SOC(y_2) = -(1-q)(p+c_u-s)f(y_1+y_2) - q(p+c_u-s)f(y_2) \leq 0. \quad (21)$$

As an analytical solution to the retailer's problem cannot be obtained without specific demand distribution functions, we provide further analysis assuming that the demand follows normal distribution below, so as to yield new insights into how demand uncertainty could impact the retailer's decisions.

3. Retailer's Optimal Order Quantities with Normally Distributed Demands.

Suppose the demand follows a normal distribution, that is, $X \sim N\ (\mu,\ \sigma^2)$. Then the value of σ^2 could represent the degree of demand uncertainty. The specific order quantity is derived first, and then the effects of demand uncertainty are investigated below.

3.1. Effects of demand uncertainty under single sourcing with contingent supply.

As the CDF of normal distribution $N\ (\mu,\ \sigma^2)$ can be written as $F(x) = 0.5(1 + Erf(\frac{x-\mu}{\sqrt{2}\sigma}))$, where $Erf(x) = \frac{2}{\sqrt{\pi}}\int\limits_0^x e^{-t^2}dt$ is the special error function, substituting it in Equations (6) and (7), we could derive the optimal decisions as

$$y_i^* = \mu + \sqrt{2}\sigma Erf^{-1}(A_i), \quad (22)$$

where

$$A_1 = \frac{(1-q)(p+c_u-2w_1+s)-2r}{(1-q)(c_u+p-s)}, \quad A_2 = \frac{p+c_u-2w_2+s-2r}{c_u+p-s}.$$

Thus we get

$$\partial y_i^*/\partial\sigma = \sqrt{2}Erf^{-1}(A_i), \quad (23)$$

which indicates that,

$$\partial y_i^*/\partial\sigma > (\leq)0 \text{ if } A_i > (\leq)0. \quad (24)$$

The result is interesting because for supplier 1, the effects of the demand uncertainty not only depends on the cost parameters (c_u, w_1, s, r) but also is determined by its disruption probability. Specifically, when $q < q_2 = (p+c_u-2w_1+s-2r)/(p+c_u-2w_1+s)$, supplier 1 could benefit from larger demand uncertainty over order quantity; while if $q > q_2$, the retailer would order less from supplier 1. As we have deduced from the previous section that, only when $q < q_1 = (p+c_u-w_1-r)/(p+c_u-w_1)$ does the retailer order from supplier 1, we next examine the relationship between q_1 and q_2.

For supplier 1, from $q_1 - q_2 = r(p+c_u-s)/(p+c_u-w_1)(p+c_u-2w_1+s)$, we have:

(1) If $(p+c_u-2w_1+s) > 0$, then $q_1 > q_2$, that is, the effects of demand uncertainty on y_1 depends on q:
   (a) if $q < (p+c_u-2w_1+s-2r)/(p+c_u-2w_1+s)$, y_1 increases with demand uncertainty,
   (b) else y_1 decreases with demand uncertainty;

(2) Else if $(p+c_u-2w_1+s) < 0$, then $q_2 > q_1 > 0$, that is, the order quantity from supplier 1 always increases with demand uncertainty.

While for supplier 2, we have:

(1) If $(p + c_u - 2w_2 + s - 2r) > 0$, then the order quantity from supplier 2 increases with demand uncertainty;
(2) Else if $(p + c_u - 2w_2 + s - 2r) < 0$, then the order quantity from supplier 2 decreases with demand uncertainty.

Besides, for both suppliers, the decrease in the wholesale price would bring more order quantity for each supplier. However, the change in demand uncertainty could also moderate the effects of wholesale prices, as we prove below:

$$\partial^2 y_1^*/\partial w_1 \partial\sigma = -2.5067 \exp\{Erf^{-1}(A_1)^2\}/(c_u + p - s) < 0, \tag{25}$$
$$\partial^2 y_2^*/\partial w_2 \partial\sigma = -2.5067 \exp\{Erf^{-1}(A_2)^2\}/(c_u + p - s) < 0. \tag{26}$$

Therefore, we can say that, as demand uncertainty increases, the possible impact of a reduction in the wholesale price on the optimal order quantity for each supplier increases.

3.2. **Effects of demand uncertainty under dual sourcing.** From Equations (18) and (19), we can derive that, under normally distributed demand,

$$\begin{aligned} &y_1^* + y_2^* = \mu + \sqrt{2}\sigma Erf^{-1}(2A_3 - 1), \\ &y_2^* = \mu + \sqrt{2}\sigma Erf^{-1}\left((2A_3 - 1) + \frac{2(A_4 - A_3)}{q}\right), \end{aligned} \tag{27}$$

where

$$A_3 = \frac{(1-q)(p + c_u - w_1) - r}{(1-q)(p + c_u - s)}, \quad A_4 = \frac{(p + c_u - w_2) - r}{p + c_u - s}.$$

Thus we have

$$y_1^* = \sqrt{2}\sigma\left[Erf^{-1}(2A_3 - 1) - Erf^{-1}\left(2A_3 - 1 + \frac{2(A_4 - A_3)}{q}\right)\right]. \tag{28}$$

It is obvious that only when $A_4 - A_3 = \frac{(w_1 - w_2)(1-q) + qr}{(p + c_u - s)(1-q)} < 0$ and $\sigma > 0$ holds, that is, $q < q_3 = \frac{w_2 - w_1}{w_2 - w_1 + r}$, the retailer would order from supplier 1. And, only when $A_4 - (1-q)A_3 > 0$, that is, $q > q_4 = \frac{w_2 - w_1}{p + c_u - w_1}$ would the retailer order from supplier 2.

Because

$$\begin{aligned} \partial(y_1^* + y_2^*)/\partial\sigma &= \sqrt{2}Erf^{-1}(2A_3 - 1) \\ &= \sqrt{2}Erf^{-1}\left(\frac{(1-q)(p + c_u - w_1 + s) - 2r - (1-q)w_1}{(1-q)(p + c_u - s)}\right), \end{aligned} \tag{29}$$

$$\partial y_1^*/\partial\sigma = \sqrt{2}\left[Erf^{-1}(2A_3 - 1) - Erf^{-1}\left(2A_3 - 1 + \frac{2(A_4 - A_3)}{q}\right)\right], \tag{30}$$

$$\begin{aligned} \partial y_2^*/\partial\sigma &= \sqrt{2}Erf^{-1}\left((2A_3 - 1) + \frac{2(A_4 - A_3)}{q}\right) \\ &= \sqrt{2}Erf^{-1}\left[\frac{((1-q)(p + c_u - 2w_1 + s) - 2r)}{(1-q)(p + c_u - s)} \right. \\ &\quad \left. + \frac{2}{q}\frac{(w_1 - w_2)(1-q) + qr}{(1-q)(p + c_u - s)}\right]. \end{aligned} \tag{31}$$

From Equation (30), if the retailer orders from supplier 1, then the order quantity always increases with demand uncertainty. While from Equations (29) and (31), the effect of demand uncertainty on the total order quantity and y_2 depend on the value of disruption probability.

Besides, we can get

$$\partial^2 y_1^*/\partial w_1 \partial \sigma - 2.5067\left[\frac{\exp\{Erf^{-1}(2A_3-1)^2\}}{c_u+p-s} + \frac{(1-q)\exp\left\{Erf^{-1}\left(2A_3-1+\frac{2(A_4-A_3)}{q}\right)^2\right\}}{q(c_u+p-s)}\right] < 0,$$

$$\partial^2 y_1^*/\partial w_2 \partial \sigma = 2.5067 \exp\left\{Erf^{-1}\left((2A_3-1)+\frac{2(A_4-A_3)}{q}\right)^2\right\} \Big/ (q(c_u+p-s)) > 0,$$

$$\partial^2 y_2^*/\partial w_2 \partial \sigma = -2.5067 \exp\left\{Erf^{-1}\left((2A_3-1)+\frac{2(A_4-A_3)}{q}\right)^2\right\} \Big/ (q(c_u+p-s)) < 0,$$

$$\partial^2 y_2^*/\partial w_1 \partial \sigma = 2.5067(1-q) \exp\left\{Erf^{-1}\left((2A_3-1)+\frac{2(A_4-A_3)}{q}\right)^2\right\} \Big/ (q(c_u+p-s)) > 0.$$

Therefore, we can say that, as demand uncertainty increases, the possible impact of a reduction in each supplier' s wholesale price or an increase in the other supplier's wholesale price on the optimal order quantity for each supplier increases.

4. **Numerical Analysis of σ's Impact on the Order Quantities and the Retailer's Expected Profit.** Without loss of generality, assume the demand follows a normal distribution, with a mean of 100 units. The numerical solutions of the order quantities can be obtained for different values of σ, and the retailer's expected profits can then be calculated accordingly. Next we will examine the effects of the value of σ under two sourcing strategies respectively.

4.1. **Analysis under single sourcing with contingent supply (SS).** First, the effects of demand uncertainty on both order quantities under different parameters are shown in Table 1.

Scenario 1 in Table 1 confirms our conclusions in Section 3.1 that if $(p + c_u - 2w_2 + s - 2r) > 0$, then the order quantity from supplier 2 increases with σ; while scenario 2 indicates that if $q > (p+c_u-2w_1+s-2r)/(p+c_u-2w_1+s)$, y_1 decreases with σ. Besides,

TABLE 1. Effects of demand uncertainty on the retailer's order quantities under SS ($s = 7$, $w_3 = 45$, $c_u = 1$)

Scenario	Order quantity	$\sigma = 5$	$\sigma = 10$	$\sigma = 15$	$\sigma = 20$	$\sigma = 25$
1	Basic parameters ($w_1 = 10$; $r = 1$; $q = 0.3$)					
$p = 50$	y_1	106.4	112.8	119.2	125.6	131.9
	y_2	99.0	98.0	97.0	96.0	95.0
$p = 100$	y_1	108.4	116.7	125.1	133.5	141.8
	y_2	103.0	106.1	109.1	112.2	115.2
2	Basic parameters ($w_1 = 30$; $r = 10$; $q = 0.6$)					
$p = 100$	y_1	99.9	99.7	99.6	99.5	99.3
	y_2	103.8	107.6	111.4	115.2	119.1
$p = 70$	y_1	96.6	93.3	89.9	86.5	83.1
	y_2	102.2	104.4	106.7	108.9	111.1

we can see that as the unit revenue increases in both scenarios, the order quantities from both suppliers also increases.

As for the effects of σ on the retailer's expected profit, Figure 1(a) gives a graphic impression based on Equation (5) with parameters setting as $p = 100$, $s = 7$, $w_1 = 10$, $w_2 = 30$, $w_3 = 45$, $c_u = 1$ and $r = 1$. It is clear that larger demand uncertainty always brings lower profits for the retailer, while larger disruption probability does not.

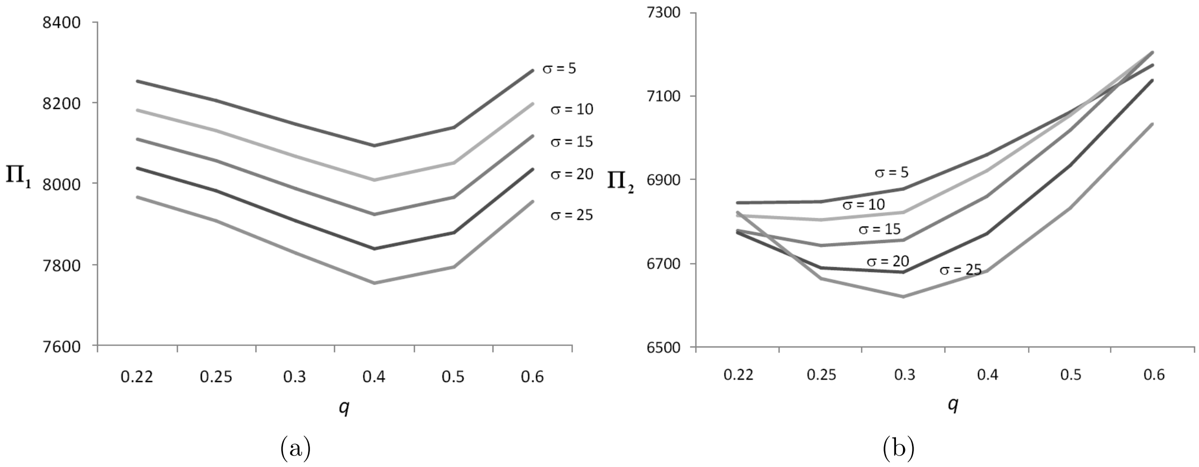

Figure 1. Effects of demand uncertainty on the retailer's expected profit

With the basic parameters setting as $p = 100$, $s = 7$, $c_u = 1$, $r = 1$ and $q = 0.22$, we examine the moderating effects of demand uncertainty related to wholesale prices in Table 2. We find that, as demand uncertainty increases, the impacts of wholesale prices on the order quantities increases. Therefore, if the demand risk is high, the retailer should pay more attention to the wholesale prices when making ordering decisions.

Table 2. Moderating effects of demand uncertainty under SS

Scenario	Wholesale price	Order quantity	$\sigma = 5$	$\sigma = 10$	$\sigma = 15$
$w_1 = 10$	$w_3 = 45$	y_2	102.5	105.0	107.4
	$w_3 = 55$		101.4	102.7	104.1
	$w_3 = 65$		100.3	100.6	101.0
$w_3 = 45$	$w_1 = 10$	y_1	108.5	116.9	125.3
	$w_1 = 15$		106.4	112.9	119.3
	$w_1 = 25$		104.1	108.2	112.4

Similar analysis is given below for situations under dual sourcing.

4.2. **Analysis under dual sourcing (DS).** From Figure 2 below, it is interesting to find that, as demand uncertainty increases, the total order quantity from both suppliers increases, while that from supplier 2 decreases. And if σ is small (less than 15 in this case), the retailer would order more from the reliable supplier. However, when the demand risk is high, the retailer would order more from the cheaper one.

Figure 1(b) already tells us the effects of demand uncertainty on the retailer's profit under DS. Next, we will examine the advantage of SS over DS under different demand uncertainties in this case, as shown in Figure 3, which indicates the value of $\Pi_1 - \Pi_2$. We find that, in most cases, smaller demand uncertainty means larger advantage of SS over DS, while larger disruption probability does not.

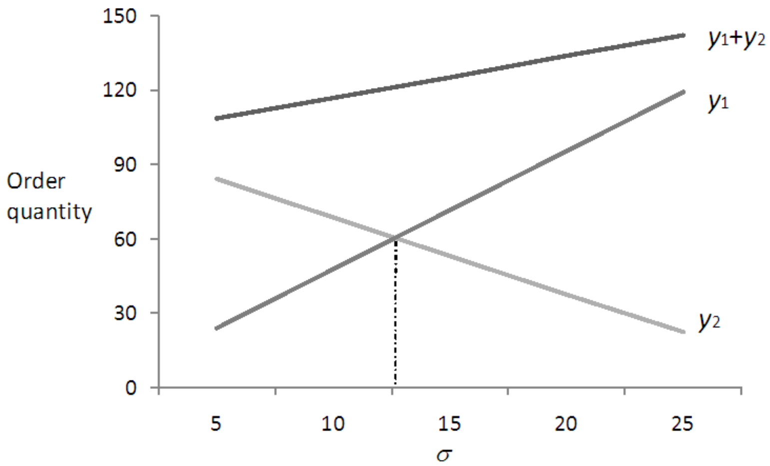

FIGURE 2. Effects of demand uncertainty on the retailer's order quantities under DS ($p = 100$, $q = 0.22$, $s = 7$, $w_1 = 10$, $w_2 = 30$, $c_u = 1$, $r = 1$)

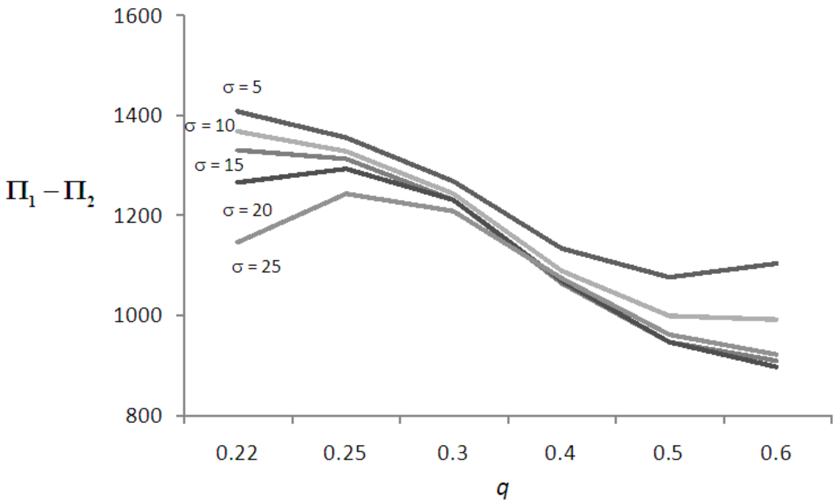

FIGURE 3. Effects of demand uncertainty on the profit difference of two sourcing strategies

Similarly, by setting as $p = 100$, $s = 7$, $c_u = 1$, $r = 1$ and $q = 0.3$, we examine the moderating effects of demand uncertainty under DS in Table 3. We find that the optimal order quantities increase (decrease) faster due to increasing wholesale prices under larger demand uncertainty.

5. **Managerial Implications and Concluding Remarks.** As supply risk management brings more attention to multiple sourcing strategies, a large quantity of the literature focuses on the impacts of various supply risks while ignoring the meanwhile effects of demand uncertainty. Considering a supply chain consists of one retailer and two suppliers of the same product, we studied the effects of demand uncertainty on the retailer's order quantities and expected profits under two sourcing strategies: single sourcing with contingent supply and dual sourcing. Compared with the existing approaches and results in the literature, which mostly studied one particular backup souring method, our research focuses on the selection between two sourcing strategies, and evaluates the impact of the demand uncertainty on the decision-making. The models we proposed can be used in the situation when the buyer, who faces supply disruptions and demand uncertainty,

Table 3. Moderating effects of demand uncertainty under DS

Scenario	Wholesale price	Order quantity	$\sigma = 5$	$\sigma = 10$	$\sigma = 15$
$w_1 = 15$	$w_2 = 20$	y_1	3.2	6.5	9.7
		y_2	103.2	106.3	109.5
	$w_2 = 30$	y_1	7.9	15.8	23.7
		y_2	98.5	97.0	95.5
	$w_2 = 40$	y_1	15.9	31.9	47.8
		y_2	90.5	80.9	71.4
$w_2 = 30$	$w_1 = 10$	y_1	11.6	23.2	34.8
		y_2	96.8	93.5	90.3
	$w_1 = 25$	y_1	2.4	5.0	7.3
		y_2	101.7	103.2	105.0

has available backup source and is willing to choose appropriate cooperation mechanism. Besides, our results could help companies better understand the effects of the demand variation and different sourcing strategies in an easy way.

Our analytical results and numerical analysis have offered the following insights. (1) The optimal order quantities may decrease or increase with the demand uncertainty, and it depends on various cost and risk parameters. Therefore, the retailer cannot just order more because of larger demand risk; he/she should first examine the values of other factors. (2) As demand uncertainty increases, the possible impact of a reduction in each supplier's wholesale price under both sourcing strategies or an increase in the other supplier's wholesale price under dual sourcing on the optimal order quantity for each supplier increases. (3) Smaller demand uncertainty brings larger profit under both sourcing strategies, and single sourcing may become more attractive over dual sourcing.

There are several interesting directions we see for future research on the decisions of sourcing strategies under supply disruption risks. First, the conditions under which one sourcing strategy outweighs the other can be investigated to better cope with various supply chain risks. Next, the profit and decisions of the two suppliers should be analyzed for each sourcing strategy. It would also be interesting to compare other kinds of sourcing strategies and help the buyer choose the appropriate one under various risk environments.

Acknowledgment. This work is partially supported by the National Nature Science Foundation of China (No. 71171050) and the National Key Technology R&D Program of China during the 11th Five-Year Plan Period (No. 2006BAH02A06) and the grant from the Humanities and Social Sciences Foundation of the Ministry of Education in China (12YJC630058). The authors are also grateful for the valuable comments and suggestions of the reviewers, which have improved the quality of the paper.

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