

Dual-source Purchasing Strategy under the Risk of Supply Disruption

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Abstract. When facing a supplier with risks, retailers usually seek a stable supplier as well to mitigate the risks and ensure a relatively stable supply. Therefore, the retailers need to decide how to procure from these two types of suppliers. To address this problem, this paper develops a dual-sourcing procurement newsvendor model that takes supply risks into account. It analyzes how retailers should procure from both high-cost but risk-free suppliers and low-cost but risky suppliers separately, to maximize their expected profits. We determine the retailer's optimal procurement strategy and observe that when the supply disruption risk is low, the retailer maintains its optimal strategy without altering it to address the risk. However, as the risk becomes more significant, the retailer tends to prefer selecting a more stable supplier.

Keywords: dual-source; supply disruption; newsvendor model.

1. Introduction

With economic globalization and the rapid development of transportation, companies can conduct procurement in larger markets, thereby reducing their costs. The comparative advantage between regions often makes overseas procurement more cost-effective than local procurement. However, cross-regional procurement can also lead to supply chain disruptions due to certain uncertainties.

For instance, in 1999, the earthquake in Taiwan resulted in significant losses for numerous purchasers who sourced from Taiwanese manufacturers [6]. Due to supply disruptions of two critical components from suppliers, Boeing Company estimated a loss of 2.6 billion USD [1]. In 2010, volcanic ash caused the inability to deliver electronic components by air to BMW, leading to the forced shutdown of three BMW factories. Similar disruptions caused by natural disasters, human interference, accidents, and other factors can have a significant impact on businesses due to supply disruptions.

To ensure a consistent supply, companies often opt for an additional reliable supplier. This strategic decision guarantees that in case of cross-regional supply disruptions, they can still procure goods and meet market demands, even though it may result in higher associated costs compared to cross-regional procurement.

Therefore, this research explores how companies maximize their expected profits by procuring from stable channels versus risky channels when there is a risk of supply disruptions from suppliers. Furthermore, when uncertainties arise and the supply in the market decreases, consumers' willingness to pay increases, leading to a rise in the prices of goods.

The remainder of this paper is organized as follows. Section 2 provides a literature review of related work. Section 3 develops a dual-sourcing procurement model under the risk of supply disruption based on single-period newsvendor model. Section 4 computes the optimal procurement strategy. Section 5 illustrates the optimal strategy and how supply disruption risk impacts the procurement strategy through a numerical example. Section 6 summarizes the conclusions and offers some insights for further consideration.

2. Related Work

In fact, numerous scholars have investigated the procurement problem under dual-sourcing and supply disruption risk using the newsvendor model. Regarding dual-sourcing procurement,

Warburton and Stratton [7] explored the optimal ordering problem considering rapid response for both onshore and offshore dual-sourcing manufacturing. Rosič and Jammernegg [5] analyzed suppliers' dual-sourcing procurement from economic and environmental perspectives utilizing the newsvendor model.

Regarding research on supply disruption risk, Dada et al. [2] examined the scenario where the purchaser procures from multiple suppliers, with suppliers categorized as reliable and unreliable, where unreliable suppliers may supply quantities lower than the purchased quantity. Ray and Jenamani [4] investigated the problem of multi-sourcing procurement for retailers based on the newsvendor model, where each supplier faces a certain probability of supply disruption. Xu et al. [10] conducted a literature review on the impact of supply disruptions on the performance loss of supply chain members.

There are also many studies that consider both supply disruption and dual or multiple sourcing procurement. Wang et al. [8] compared the effectiveness of dual-sourcing procurement and process improvement in mitigating supply risk under different circumstances. Han et al. [3] adopted a robust optimization approach to explore how the purchaser should procure from a primary supplier and a backup supplier when there is a risk of supply disruption from the primary supplier. Xanthopoulos et al. [9] used the newsvendor model to study procurement strategies under dual sourcing, where each supplier faces a certain probability of supply disruption risk. Yu et al. [11] simultaneously considered dual sourcing and supply disruption, comparing the optimal strategies and expected benefits of single sourcing and dual sourcing for companies with elastic random demands.

However, the above-mentioned studies either did not consider prices and modeled from the perspective of minimizing expected costs, or they assumed that commodity prices are exogenous, without considering the endogenous aspects of stochastic demand and price fluctuations. In this paper, we investigate the problem of purchasers procuring from both a stable (local) supplier and a risky (foreign) supplier when supply disruptions lead to changes in market prices.

3. Model

We consider a market where retailers face random demand, and the demand follows a uniform distribution on the $[\underline{d}, \bar{d}]$, where \underline{d} represents the minimum demand, and \bar{d} represents the maximum demand. Therefore, the probability density function of the demand is denoted as $f(d) = \frac{1}{\bar{d} - \underline{d}}$.

The retailer purchases q_1 units of goods from company 1 and q_2 units of goods from company 2.

Company 1 can deliver the goods reliably each time. However, company 2 carries a supply risk with a probability of θ , which means that there is a chance that the ordered goods may not be delivered in a given period. The marginal cost of ordering goods from company 1 is denoted as c_1 , while from company 2 it is denoted as c_2 . To ensure that the retailer does not only purchase goods from company 1, it is assumed that $c_1 > c_2$.

At the same time, we assume that the price of goods will decrease with an increase in their supply. This assumption is reasonable because when supply disruptions occur and the supply of goods decreases, the market may be willing to pay increased prices for goods.

In order to simply illustrate the relationship between price and supply, we set the supply function as follows:

$$p = p_0 - \lambda * q, \quad (1)$$

where p_0 represents the upper bound of the price that consumers are willing to pay for the goods, and λ is the influence coefficient of output on price. Moreover, to ensure that the retailer's profit is positive, we assume that $p > c_1 > c_2$.

Based on the above setup, we consider a single-period newsvendor model, where the retailer's supply quantity is $q_1 + q_2$ when there is no supply disruption, and it is q_1 when a supply disruption

occurs. When the purchased quantity exceeds the current demand, that is $q \geq d$, retailer supply can meet all demand, and the remaining goods will be recycled with the salvage value of m . Usually, the salvage value is lower than the cost, so we assume that $m < c_2$. When the supply quantity exceeds the maximum possible demand, there will inevitably be a surplus. In this case, the order quantity being equal to the maximum possible demand of goods is always preferred over exceeding it, that is $q \leq \underline{d}$. When $q < d$, because the demand is not fully met, the retailer can only sell the goods according to the purchased quantity. According to the different demand satisfaction conditions mentioned above, we establish the retailer's utility function as follows:

$$\Pi(q_1, q_2) = \begin{cases} (p_0 - \lambda q)d - c_1 q_1 - c_2 q_2 + m(q - d) & (p_0 - \lambda q)d - c_1 q_1 \\ -c_2 q_2 + (p_0 - \lambda q)(q - d), & d < q \leq d \leq q \end{cases} \quad (2)$$

where $q = q_1 + q_2$ and when the supply disruption occurs, no matter how much q_2 the retailer orders from the international supplier, the actual order quantity is 0.

According to Equation (2), we can calculate the retailer's expected profit $E(\Pi(q_1, q_2))$ when there is no supply disruption as follows:

$$\begin{aligned} E(\Pi(q_1, q_2)) &= \int_{\underline{d}}^{\underline{d}} (p_0 - \lambda q)xf(x)dx - c_1 q_1 - c_2 q_2 \\ &+ m \int_{\underline{d}}^q (q - x)f(x)dx \\ &+ (p_0 - \lambda q) \int_q^{\underline{d}} (q - x)f(x)dx. \end{aligned} \quad (3)$$

Similarly, when $q_2 = 0$, we can obtain the expected utility for the case of supply disruption as $E(\Pi(q_1, 0))$. Therefore, we can express the retailer's total expected profit as follows:

$$E(\Pi) = (1 - \theta)E(\Pi(q_1, q_2)) + \theta E(\Pi(q_1, 0)) \quad (4)$$

4. Optimal action

To compute the retailer's maximum expected utility for purchasing, we take the first partial derivatives of formula (4) with respect to q_1 and q_2 , and calculate as follows:

$$\frac{\partial E(\Pi)}{\partial q_1} = (1 - \theta) \left(-\frac{\lambda}{2} (\underline{d} + \underline{d}) - c_1 + m \frac{(q_1 + q_2 - \underline{d})}{(\underline{d} - \underline{d})} + \lambda \frac{(\underline{d} - q_1 - q_2)^2}{2(\underline{d} - \underline{d})} + (p_0 - \lambda(q_1 + q_2)) \frac{(\underline{d} - q_1 - q_2)}{(\underline{d} - \underline{d})} \right) + \theta \left(-\frac{\lambda}{2} (\underline{d} + \underline{d}) - c_1 + m \frac{(q_1 - \underline{d})}{(\underline{d} - \underline{d})} + \lambda \frac{(\underline{d} - q_1)^2}{2(\underline{d} - \underline{d})} + (p_0 - \lambda q_1) \frac{(\underline{d} - q_1)}{(\underline{d} - \underline{d})} \right), \quad (5)$$

$$\begin{aligned} \frac{\partial E(\Pi)}{\partial q_2} &= (1 - \theta) \left(-\frac{\lambda}{2} (\underline{d} + \underline{d}) - c_2 + m \frac{(q_1 + q_2 - \underline{d})}{(\underline{d} - \underline{d})} \right. \\ &\left. + \lambda \frac{(\underline{d} - q_1 - q_2)^2}{2(\underline{d} - \underline{d})} + (p_0 - \lambda(q_1 + q_2)) \frac{(\underline{d} - q_1 - q_2)}{(\underline{d} - \underline{d})} \right). \end{aligned} \quad (6)$$

Further, we calculate the Hessian matrix as follows:

$$H = \begin{bmatrix} \left(\frac{1}{\underline{d} - \underline{d}}\right)M & \left(\frac{1 - \theta}{\underline{d} - \underline{d}}\right)M & \left(\frac{1 - \theta}{\underline{d} - \underline{d}}\right)M & \left(\frac{1 - \theta}{\underline{d} - \underline{d}}\right)M \end{bmatrix} \quad (7)$$

where $M = (m - 2\lambda(\underline{d} - q_1 - q_2) - (p_0 - \lambda(q_1 + q_2)))$.

Due to $\underline{d} - q_1 - q_2 > 0$ and $p_0 - \lambda(q_1 + q_2) - m > 0$, we can deduce that $M < 0$, indicating that Equation (7) is a negative definite matrix. Therefore, there exists a maximum point (q_1^*, q_2^*) such that $\frac{\partial E(\Pi)}{\partial q_1} = 0$ and $\frac{\partial E(\Pi)}{\partial q_2} = 0$ where the retailer's expected profit is maximized.

Substituting (q_1^*, q_2^*) into Equation (6), we obtain the following:

$$c_2 = -\frac{\lambda}{2}(\underline{d} + \underline{d}) + m \frac{(q_1^* + q_2^* - \underline{d})}{(\underline{d} - \underline{d})} + \lambda \frac{(d - q_1^* - q_2^*)^2}{2(\underline{d} - \underline{d})} + (p_0 - \lambda(q_1 + q_2)) \frac{(d - q_1^* - q_2^*)}{(\underline{d} - \underline{d})} \quad (8)$$

Substituting Equation (8) into Equation (6), we obtain the following:

$$(1 - \theta)(c_2 - c_1) + \theta \left(-\frac{\lambda}{2}(\underline{d} + \underline{d}) - c_1 + m \frac{(q_1^* - \underline{d})}{(\underline{d} - \underline{d})} + \lambda \frac{(d - q_1^*)^2}{2(\underline{d} - \underline{d})} + (p_0 - \lambda q_1^*) \frac{(d - q_1^*)}{(\underline{d} - \underline{d})} \right) = 0 \quad (9)$$

We can observe that Equation (9) is a function of q_1^* . Therefore, by solving for the roots of Equation (9), we can calculate q_1^* . Substituting q_1^* into Equation (6), we can then calculate q_2^* .

5. Numerical example

In this section, we will verify the above results using a numerical example. Let $c_1 = 10$, $c_2 = 6$, $p_0 = 15$, $\lambda = 0.0001$, $m = 2$, $\underline{d} = 8000$, $\underline{d} = 3000$, and $\theta = 0.3$. We obtained the retailer's expected profit as a function of q_1 and q_2 , as shown in figure 1.

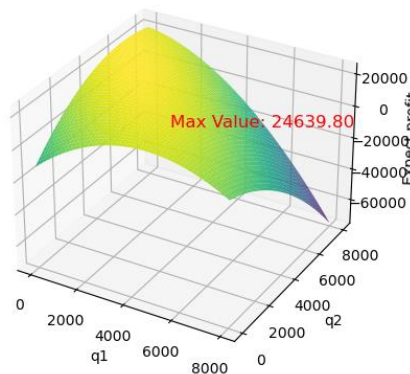


Fig 1. The variation of expected profit

We calculated that when $q_1^* = 1212.12$ and $q_2^* = 4929.29$, the purchaser's expected profit is maximized at 24639.80. Next, we compared the optimal order quantities for different θ values, considering the case where $\theta = [0,1]$. The results are shown in Figure 2.

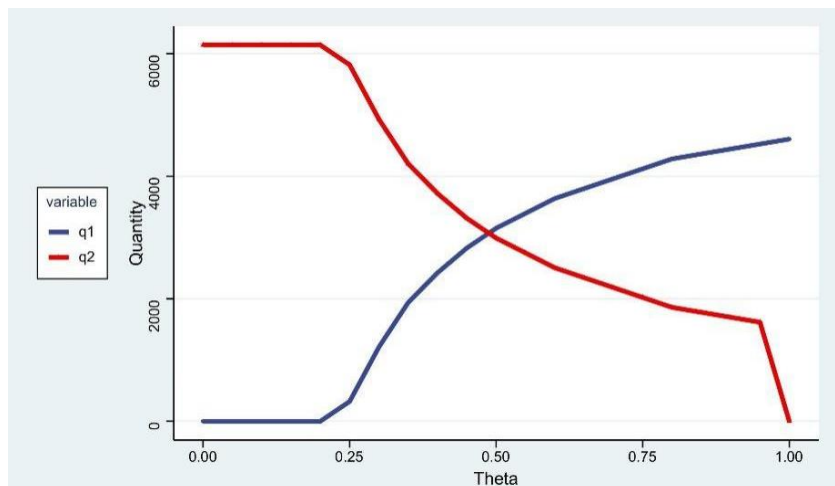


Fig 2. Impact of probability of supply disruption on purchase quantity

In Figure 2, we found that as the supply disruption risk increases, the retailer initially continues to procure only from the riskier but lower-cost Company 2. In reality, such situations also exist where retailers, faced with a very low probability of risk occurrence, tend not to choose stable suppliers for procurement. This practice may lead to significant losses when disruptions occur. However, it still remains more cost-effective than procuring from stable suppliers to mitigate risks. As the risk increases, the retailer gradually starts choosing to order more goods from stable suppliers. When the

probability of risk occurrence becomes very high, the retailer will no longer procure from company 2.

6. Conclusion

This paper has shown a newsvendor model with a dual-sourcing strategy under supply disruption risk, where one supplier has lower costs but carries the risk of disruptions, while the other has higher costs but no supply risk. Additionally, we innovatively introduce the case of price variation with supply quantity and discuss how supply disruptions not only change the retailer's procurement strategy but also affect market price expectations for the product. Based on this, we discuss the retailer's optimal procurement strategy. We find that there always exists an optimal procurement strategy that maximizes expected profit for the retailer. Through numerical examples, we observe that as the risk increases, the retailer does not necessarily increase the procurement quantity from stable suppliers. Only when the risk exceeds a certain threshold, the retailer will start procuring from stable suppliers to mitigate profit losses caused by disruptions.

However, our research has limitations. We only discuss the case of simple random distributions and consider only simple linear relationships for price variations. In the future, these assumptions can be relaxed to more general cases to discuss optimal strategies under broader circumstances.

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