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Diversification strategy with random yield suppliers for a mean–variance risk-sensitive manufacturer

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ABSTRACT

We consider the diversification strategy for a mean–variance risk-sensitive manufacturer with unreliable suppliers. We first analyze the linear model and find that the suppliers are selected according to the descending order of their contributed marginal expected profit, and increasing the manufacturer's risk-averseness leads to a more even allocation of demand across the suppliers. Then, we study the general newsvendor model. By approximating the leftover inventory with a normal distribution, we establish the general properties of the active supplier set and show that the supplier selection rule is similar to that under the risk-neutral setting when the demand uncertainty is large. Moreover, we conjecture that the selection rule also applies when the demand uncertainty is low, which we verify with an extensive numerical study. Our paper makes two contributions: First, we establish the properties of the optimal diversification strategy and develop corresponding insights into the trade off between cost and reliability under the mean–variance framework. Second, we perform comparative statics on the optimal solution, with a particular emphasis on investigating how changes in the supplier's cost or reliability affect the risk-averse manufacturer's ordering decisions and customer service level.

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1. Introduction

With the globalization of supply chain operations, many firms face risks from both the supply side (i.e., supply uncertainty) and the demand side (i.e., demand uncertainty). Supply uncertainty arises due to factors such as major machine malfunctions, damage during transportation, human-centered issues such as fraud and strike, natural hazards, terrorism, and political instability (see Kleindorfer and Saad, 2005). With supply uncertainty, the quantity of goods received by the firm may be less than the quantity ordered. For example, Starbucks may find that, in addition to the agreed price, the quality and quantity of the coffee beans supplied by farmers may vary as the weather varies. Diversification of suppliers is a fundamental strategy for effectively managing the supply risk. In operations management, an extensive body of literature studies the problems of supplier diversification. These studies focus on different aspects of the problem, varying from the allocation of demand among suppliers to the trade-off between reliability and procurement cost and the interplay between supplier diversification and flexible resources. For instance, Bernstein et al. (2015) argue that a manufacturer cannot mitigate the supply risk simply by diversifying its suppliers, which is modeled by a Bernoulli distribution, when the profit function is “linear”

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in the expected delivery quantity. They thus argue that the shape of the revenue and cost functions leads to the respective supplier diversification strategies. However, they consider the problem in a risk-neutral setting only.

It is well established in the literature that decision makers have preferences other than risk neutrality. Risk aversion is a common decision preference. Pioneered by Markotwiz (1959) in the 1950s, the mean–variance framework has become the building block of modern financial theories. In fact, variance is a natural measure of risk. When variance is the measure of risk, the diversification strategy can reduce the supply risk even when the profit function is “linear” in the expected delivery quantity. Consider the following example. A manufacturer uses two independent suppliers to produce two units of a particular component. Suppose that the unit production cost for both suppliers is identical and denoted as c and the unit selling price for the product is p . All other expenses are negligible. The two suppliers face the risk of a natural disaster, described by a Bernoulli random variable with a probability of M in the normal state and thus a probability of $1 - M$ in the disruptive state. If the manufacturer diversifies by sourcing one component from each supplier, its expected profit is $2M(p - c)$. Using a single source, its expected profit is again $2M(p - c)$. However, the profit variance when sourcing from both suppliers is $2M(1 - M)(p - c)^2$ and the profit variance when sourcing from one supplier is $4M(1 - M)(p - c)^2$. Thus, even if the expected profit is the same for both strategies, supplier diversification can mitigate the risk by reducing the profit variance.

In this paper we consider a monopoly manufacturer who acts as the buyer, he sources components from a portfolio of suppliers and assembles the components, then sells the final product. Suppliers are unreliable and supply uncertainty is modelled with respect to the proportional yield. Different suppliers have different level of reliability. The more reliable the supplier, the more expensive the procurement cost for the manufacturer is. The manufacturer makes component ordering decisions to balance the risk of uncertain supply, and the associated profit generated from sales to maximize his utility, which is measured by mean–variance. For the linear revenue model, we characterize the diversification strategy and find that the suppliers are selected in the ascending order of their contributed marginal expected profit. Moreover, we find that the order quantities of those suppliers increase even when the manufacturer is more risk averse. For the general newsvendor model, we approximate the leftover inventory by the normal distribution and establish the properties of the active supplier set, then develop the optimal diversification strategy with the corresponding algorithm when the demand uncertainty is high; that is, active suppliers are chosen in an ascending order of their effective marginal cost. Based on an extensive numerical study, we further propose a conjecture, which implies that the selection rule also applies when the demand uncertainty is low. Finally, we perform comparative statics on the optimal solution, with a particular emphasis on investigating how changes in a supplier’s cost or reliability affect the risk-averse manufacturer’s ordering decisions and customer service level.

The rest of this paper is organized as follows. In Section 2, we review the related literature. In Section 3, we formulate the problem and analyze the linear revenue model and the newsvendor model. In Section 4, we carry out numerical studies. We conclude our study and discuss future research directions in Section 5.

2. Literature review

This paper is related to several streams of research in inventory management. The first stream examines how the supply risk affects the performance of inventory management. Natural disasters such as hurricanes, earthquakes, tsunamis, human-centered issues such as fraud and strike, and machine malfunctions can all lead to supply uncertainty. The management of supply risk has attracted considerable attention from both practitioners and researchers in the inventory management field. Related research considering yield risk in inventory management has been carried out in various ways, including with single- or multi-period, single- or multi-stage, single- or multi-products, and single or multiple suppliers. We focus on the multiple supplier, one product procurement problem, where suppliers’ uncertainties are modeled with random yield. For other settings, we refer readers to the excellent reviews by Yano and Lee (1995), Grosfeld-Nir and Gerchak (2004), Tang (2006), Vakharia and Yenipazarli (2008), and Sadghiani et al. (2015) and the references therein. Almost all studies that consider random yield assume a single supplier. Parlar and Wang (1993) are among the first to demonstrate the benefits of dual sourcing in the presence of supply uncertainty. Anupindi and Akella (1993) and Swaminathan and Shanthikumar (1999) consider the total cost model with two suppliers. These authors also generalize some of their results to allow for multiple periods. Yano and Lee (1995) explain that the complexity of dealing with a general set of suppliers is extreme and hence it is difficult to obtain structural results. Recently, Tang and Kouvelis (2011) study supplier diversification strategies in the presence of yield uncertainty and buyer competition. Chaturvedi and Martínez de Albéniz (2011) analyze the optimal procurement auction mechanism with unreliable supply. They design optimal mechanisms that depend on the buyer’s level of information regarding the supplier’s cost of production and reliability. Giri (2011) studies the sourcing problem from two unreliable suppliers, who differ in their reliability and selling price. They investigate the optimal procurement policy in a risk-neutral setting and carry out the numerical study in a risk-averse setting, where an exponential utility function is used to measure the decision maker’s risk attitude. Cheong and Song (2013) study the value of information on supply risk under random yields within a newsvendor framework.

In addition to the literature dealing with no more than two suppliers with supply risk, Agrawal and Nahmias (1997) seem to be the first work to consider the procurement problem with multiple unreliable suppliers, where supply uncertainty is modeled with random yield. The yield rates are assumed to be independent and normally distributed. Demand is deterministic and they also consider fixed order costs in their model. When the suppliers are identical, they find the optimal number of suppliers and order quantities. However, when the suppliers are not identical, they show the complexity of the optimization problem and focus on the dual sourcing problem. Chen et al. (2001) investigate the inventory control problem with

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