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Dynamic Pricing and Inventory Management for Systems
with Dual Unreliable Suppliers
Xiuli Chao\textsuperscript{1}, Xiting Gong\textsuperscript{2}, and Shaohui Zheng\textsuperscript{3}

Extended Abstract

\textbf{Introduction.} It is common for firms to have unreliable suppliers that are exposed to some risk of disruption due to natural disasters, accidents, strikes or other events. Without some effective mitigation strategies, a supply disruption may cause very significant losses. Ericsson, for example, suffered lost sales of at least US$400 million due to a fire at a Philips plant in 2000, which was Ericsson’s only supplier of a particular micro-chip ([3]); Honda was forced to shut down many of its plants for several weeks due to shortage of parts caused by a series of strikes in China auto industries in 2010 ([1]); the Taiwan earthquake in 1999 and the recent Japan earthquake and the following tsunami and nuclear disaster also caused major disruptions to supply chains in electronics and other industries. To mitigate the risk of supply disruption, many firms use multiple suppliers for replenishment, and naturally, it brings out the following important questions: How to effectively manage an inventory system with multiple unreliable suppliers? And how do source diversification and the reliability of suppliers affect the firm’s optimal operational decisions, market share, profitability, and its customers? In this study, we aim to address some of these questions by studying a dynamic integrated inventory and pricing model with dual unreliable suppliers.

\textbf{The Model.} We consider a firm that sells a single product over a planning horizon of multiple periods. The firm has two potential suppliers and there is a constant unit procurement cost when ordering from each supplier. Both suppliers may suffer random disruption in each period. Specifically, if a supplier encounters a disruption in a period, then it is unable to deliver any order in this period; while if a supplier has no disruption in a period, then it is reliable and can fully deliver any order placed in this period with zero lead time. The disruption processes of the two suppliers are assumed to be independent of each other and each of them is characterized by a Markovian Bernoulli process with known transition probabilities. The demands in consecutive periods are independent and price-sensitive random variables. We assume an additive demand model, i.e., the random demand in each period equals a deterministic function of the current-period price plus a price-independent random variable. Any unsold product at the end of each period is carried to the next period incurring unit holding cost; and any unsatisfied demand is backlogged incurring unit backlog cost. Similar to many studies in the literature (e.g., [2]), we assume that a customer pays the price in the period when she places her order and the firm’s expected sales revenue is a concave function of the mean demand. The firm’s objective is to jointly optimize its ordering and pricing decisions to maximize its expected total discounted profit over the planning horizon.

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We formulate the firm’s optimization problem as a stochastic dynamic program. The state variables in each period consist of the initial inventory level in this period and the delivery capabilities of the two suppliers in the previous period; and the decision variables in each period include the ordering quantities from the two suppliers and the selling price of the product. To address the above research questions, we first characterize the structure of the firm’s optimal policies and then study the impacts of source diversification and supplier reliability on the firm and its customers. Our main results and contributions are summarized as follows.

**Main Results and Contributions.** Our main results and contributions are threefold. The first major result is to characterize the structure of the firm’s optimal policies and their dependencies on the state variables. For brevity, we only present part of the result in the following.

**Theorem 1** In each period, the optimal ordering policy is of a threshold type and the optimal ordering quantities and the optimal price all decrease in the initial inventory level. In particular, if only one of the suppliers is unreliable, then the optimal ordering policy is of a base-stock type and the optimal pricing policy is a list-price policy with markdowns.

This result shows that in each period there exists a threshold value for each supplier such that it is optimal to order from this supplier if and only if the initial inventory level is below this threshold. Thus, the structure of the optimal policies is more complicated than the corresponding problem without supply disruptions, where a base-stock list-price policy is known to be optimal (see, e.g., [2]). However, for the special case when only one supplier is unreliable, the optimal policies become simpler and have a certain base-stock list-price structure.

The next major result summarizes the impacts of unit ordering costs on the firm and its customers, which reveals some important insights about source diversification.

**Theorem 2** If the unit ordering cost from one supplier increases, then in each period the firm’s optimal profit and its optimal ordering quantity from this supplier both decrease while the optimal price and the optimal target safety stock level for ordering from the other supplier both increase. In particular, if the selling price is fixed and not a decision, then the optimal ordering quantity from the other supplier also increases.

Theorem 2 shows how the firm’s optimal profits and the optimal policies depend on the unit ordering costs from the suppliers. More importantly, notice that when one supplier’s unit ordering cost becomes large enough, this supplier will never be used and the problem then reduces to a system with only one (unreliable) supplier. Therefore, Theorem 2 implies the following result.

**Corollary 3** For a system with a single unreliable supplier, if an additional supplier is introduced, then in each period the firm’s optimal profit increases while the optimal selling price decreases.

Hence, we conclude that source diversification not only helps increase the firm’s profit but also benefits its customers. To the best of our knowledge, this result is the first to address the impact of source diversification on the firm’s customers.
Our last major result shows how the firm’s optimal profits and the optimal policies depend on the reliability of the suppliers, which is quantified by the suppliers’ delivery probabilities or the transition probabilities of the Markovian Bernoulli processes.

**Theorem 4** If either supplier’s reliability increases, then the firm’s optimal profit in each period increases while its optimal price in the last period decreases. Particularly, if only one of the suppliers is unreliable and its reliability increases, then the firm’s optimal price in each period decreases. In addition, when compared to the model when both suppliers are unreliable, the firm will charge a lower optimal price in each period when only one of them is unreliable.

Theorem 4 shows that the firm always benefits from higher reliability of the suppliers. Unfortunately, since the multi-period problem with two unreliable suppliers is too involved to analyze, we are only able to show that the optimal price drops in the last period when the suppliers’ reliability increases. Nevertheless, for the special case when only one of the suppliers is unreliable, we can extend this result to an arbitrary period, which shows that higher supplier reliability also benefits the customers. Also, it continues to hold for every period when one supplier improves from being unreliable to perfectly reliable. To this best of our knowledge, this result is also the first to address the impact of supplier reliability on the firm’s customers.

In addition to the above major results, many other interesting results are also obtained revolving our research questions. Several numerical examples are also provided to explore further managerial insights. Taken together, besides characterizing the optimal policies, our study conveys that source diversification or higher supplier reliability in general benefits both the firm and its customers.

**Methodologies.** The main technical approach used in this study is lattice and modularity analysis. [4] provides a comprehensive account on this type of analysis; and Theorem 2.7.6 (preservation of supermodularity under maximization operations) and Theorem 2.8.2 (monotone optimal policies) therein are frequently used in deriving our theoretical results. Meanwhile, it is worth mentioning that in order to prove Theorem 4 we also establish two new preservation results, which we expect to have applications in other supply chain control problems.

**References**


