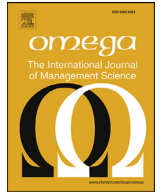




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Sourcing strategies for a capacitated firm subject to supply and demand uncertainty

Nickolas Freeman^{a,b,*}, John Mittenthal^b, Burcu Keskin^b, Sharif Melouk^b

^a University of Houston, USA

^b Department of Information Systems, Statistics, and Management Science The University of Alabama Tuscaloosa, AL

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ABSTRACT

We study sourcing strategies for a capacitated manufacturer subject to supply and demand uncertainty. The manufacturer produces two products: low- and high-quality versions of the same product that differ in only one critical component. For the low-quality product, one supplier of the critical component is unreliable, failing to deliver ordered components with some positive probability. To mitigate the risk associated with the unreliable supplier, the manufacturer may: *i*) order from a perfectly reliable, but expensive secondary supplier (i.e., dual sourcing); *ii*) produce some or all of the component in-house (i.e., concurrent sourcing); or *iii*) substitute a higher quality component (i.e., downward substitution). All production activities share a limited capacity resource. We develop a stochastic programming formulation in a single period setting to study the optimal combination of these sourcing tactics, which we refer to as sourcing strategies, under a variety of conditions. An extensive screening experiment reveals that five of the 63 possible sourcing strategies occur as the optimal sourcing strategy in nearly 75% of problem instances. Additional experiments provide insight into the impact of limited capacity, the value of each available sourcing option, and the evolution of the optimal sourcing strategy as key problem parameters change. Most interestingly, our experiments reveal that the ability to produce a component in-house is a highly effective means for mitigating supply and demand uncertainty in a wide range of problem environments.

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1. Introduction

An increasing amount of academic research focuses on strategies to mitigate supply uncertainty arising in a supply chain. To attain tractable models, most researchers consider a single firm that may source from two or more suppliers subject to Bernoulli yields, e.g., each supplier is either in an “up” state, having unlimited supply capacity, or a “down” state, having zero supply capacity. A supplier in the down state is commonly said to be disrupted. Most studies considering such a situation focus on two types of mitigation strategy: (1) routine sourcing and (2) contingent rerouting. Routine sourcing strategies mitigate supply uncertainty by ordering a single good from multiple suppliers simultaneously, i.e., supply diversification. Research that considers routine sourcing typically focuses on determining a supplier base and splitting orders among the suppliers. Contingent rerouting is an extension of routine sourcing where the buying firm utilizes

a backup, or emergency supplier, upon observing a disruption to one or more members of their supplier base [19].

The recent survey of [19] suggests that although mitigation strategies for supply disruptions have received considerable attention in the literature, most models still consider a rather limited set of the tactics that firms employ. Moreover, the authors suggest that a promising area for future research lies in investigating the value and optimal use of multi-pronged mitigation strategies that consider an extended set of tactics. In this paper, we consider the simultaneous use of dual sourcing (a form of routine sourcing), concurrent sourcing (a kind of contingent rerouting), and downward substitution for mitigating the risk of supply disruptions.

Concurrent sourcing refers to the practice of simultaneously procuring and producing some component. Empirical studies suggest that a large number of firms employ concurrent sourcing [14]. For example, Toyota invested in the technology necessary to produce higher-end electronic components in-house to reduce their dependency on external suppliers and attain the capacity to absorb supply and demand fluctuations [2]. In the metal forming industry, a survey of 193 respondents indicated that concurrent sourcing is employed for 28% of products to aid in the assessment

* Corresponding author.

E-mail address: nkfreeman@cba.ua.edu (N. Freeman).

of costs and market prices [15]. In light of the existing literature, concurrent sourcing is essentially a form of contingent rerouting in which the capability to produce in-house represents a backup supply source. This classification is valid when capacity is unlimited or resources are dedicated to in-house production, but does not hold in situations where in-house production consumes resources that are shared with other production activities. In such cases, the decision to use in-house production reduces the amount of capacity available for other activities. Ultimately, concurrent sourcing may be viewed as a tactic that improves the resiliency of a supply chain, i.e., the ability of a supply chain to sustain operations during a disruption [20].

Downward substitution occurs when a firm substitutes a higher quality component in place of a lower quality component. This practice is common in both manufacturing and service industries. Examples include a computer manufacturer substituting a larger capacity memory chip for a lower capacity memory chip, and car rental companies “upgrading” customers if their preferred selection is not available. A recent survey conducted by MIT and PriceWaterhouseCoopers found that 48% of the 209 respondents employ some form of product substitution as a means to mitigate supply risk [13]. As with concurrent sourcing, a trade-off exists when considering the use of downward substitution. In particular, employing downward substitution reduces the available quantity of the higher quality component. Moreover, using a higher quality input as a substitute results in additional production cost, thus reducing the associated profit.

We consider the optimal use of dual sourcing, concurrent sourcing, and downward substitution for a manufacturing firm subject to demand and supply uncertainty. The firm produces two products that differ in the quality of one critical component. The manufacturer sources the high-quality component from a single, perfectly reliable supplier, while two suppliers (supplier U and supplier R) are available for the lower quality component. Supplier U is unreliable, experiencing a disruption with some positive probability, in which case no ordered components are delivered. Supplier R is a perfectly reliable source for the lower quality component but is more expensive. In addition to using dual sourcing to mitigate a supply disruption of the low-quality component, the manufacturer may use concurrent sourcing or employ downward substitution. In contrast to existing works:

1. We consider the production capacity of the manufacturer to be limited and shared between finished goods production and in-house component production. In such a setting, producing components in-house reduces the amount of capacity available for finished goods production.
2. We consider downward substitution as a risk mitigation lever that may be employed regardless of disruption occurrence. Existing studies only consider downward substitution as a means to adjust the availability of a product after realizing the outcome of some uncertain event. In our study, the decision to use downward substitution is made before the occurrence of a disruption is realized. We assume that the high-quality component is more expensive than the low-quality component so that downward substitution incurs a cost in the form of reduced profit margins for finished products that use substituted components.

Our research focuses on identifying combinations of the described sourcing tactics, also referred to as sourcing strategies, which are best able to mitigate the supply and demand uncertainty faced by the manufacturer. We develop a stochastic programming formulation that seeks to maximize the firm’s expected profit for this purpose. We conduct experiments that study the optimal sourcing strategy in a wide variety of problem settings, i.e., combinations of parameter values. Our experiments show

that only 16 of the 63 possible sourcing strategies occur as an optimal sourcing strategy for at least one of the problem settings. A closer examination of five sourcing strategies that are optimal in nearly 75% of the problem settings demonstrates the parameter interactions affecting the manufacturer’s expected profit. Finally, we study the value of each sourcing tactic independently by observing the reduction in profit that occurs when a particular sourcing tactic is unavailable. For example, we study the value of in-house production capabilities by investigating a case where this sourcing tactic is not possible and comparing the associated profit to that obtained when all sourcing tactics are available. This latter experiment suggests that a sourcing strategy that employs routine and concurrent sourcing performs near-optimally under most circumstances. Although downward substitution can improve the manufacturer’s expected profit, we observe that its primary use is as a means to shift capacity allocations among the various production activities. Overall, our results suggest that in-house production capabilities offer the most substantial reduction in the risk resulting from the possibility of a supply disruption.

The remainder of the paper is organized as follows. We provide a brief discussion of related literature in Section 2. In Section 3, we formally describe the problem along with its assumptions. In Section 4, we present a stochastic programming formulation for our problem. The results of an extensive set of experiments focusing on the five sourcing strategies that most frequently occur as optimal, the value of each component a procurement option, and the impact of capacity on the optimal sourcing strategy are presented in Section 5. We conclude with managerial insights and extensions of our work in Section 6.

2. Literature review

The recent review by Snyder et al. [19] includes a thorough survey of routine sourcing research. One major theme is that cost trumps reliability when selecting suppliers. Specifically, several works considering a single firm that must procure from unreliable suppliers show that an order may be placed with a particular supplier i only if orders are also placed from all suppliers that are cheaper than supplier i . Moreover, the majority of works find diversification to be an important component of an effective strategy for mitigating supply risk. Aside from selecting suppliers, many works focus on the problem of allocating orders among a set of selected suppliers. Most recently, Hu and Kostamis [8] show that when ordering from one reliable supplier and one unreliable supplier, the total order quantity decision and the allocation of the order to the two suppliers may be addressed independently.

Several works in the OR/MS literature consider the role of in-house production in the optimal sourcing strategy for a manufacturing firm. Many of these works focus on setting prices and determining contracts with external supplier when the capacity for in-house production is insufficient to satisfy all demand or demand is uncertain [9–11]. In an early work, Ahmadi and Tang [1] study the ordering decisions of a manufacturer with in-house production capabilities that are insufficient to satisfy demand over a finite planning horizon. To overcome the shortfall, the manufacturer may source some amount of their total requirements from an external supplier. The authors focus on computational methods for solving the problem and develop two Lagrangian-based heuristics that produce near-optimal allocations that specify the amount of total requirements produced in-house and ordered from the external supplier. Yang et al. [21] extend the work of Ahmadi and Tang [1] to consider the case where demand is stochastic and in-house production is subject to yield loss. They show that supplementing in-house production with an order from the external supplier is most beneficial when the external supplier is cheaper than producing in-house, the mean demand is much higher than the

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