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Backup sourcing with capacity reservation under uncertain disruption risk and minimum order quantity

Jing Hou [a,*], Amy Z. Zeng [b], Li Sun [a]

[a] Business School, Hohai University, Nanjing, Jiangsu 211100, PR China
[b] Robert A. Foisie School of Business, Worcester Polytechnic Institute, Worcester, MA 01609, USA

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ABSTRACT

Ample evidence has confirmed the importance of backup sourcing when disruption of the major supply source is inevitable. The decisions associated with how to work with the backup supplier to ensure backup or emergency supply when the primary source experiences shortfall have received a great deal of attention. We study a capacity reservation contract between a buyer and a backup supplier when there is uncertainty about the major supplier's disruption risks. Additionally, we consider the constraint that requires the buyer to order either none or at least a minimum order quantity in the case of contingent sourcing. By committing to such backup contracts, the buyer seeks to lower its contingent purchasing cost and to ensure the availability of merchandise in the presence of risks. The involving players' optimal decisions are investigated theoretically and the impacts of the key parameters and special scenarios are assessed numerically. The study contributes to the literature by providing a better understanding of how to use a capacity reservation contract as a vehicle to build long-term relationship in backup sourcing and of the impacts of disruption uncertainty and contingent supply availability.

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1. Introduction

From the "Black Swan" tragedy of 9–11 to recent natural disasters, it is seen clearly that the world is becoming increasingly VUCA (volatile, uncertain, complex, and ambiguous). As such, global supply chains frequently experience disruptions, ranging from major breakdowns because of natural or man-made disasters to minor interruptions due to equipment shortage, sick workers, and others. A breakdown at any point of a supply chain could cripple the entire chain's continuity and normal operation. Parameters describing the profile of a disruption include magnitude or severity, frequency, likelihood or probability of occurrence, and duration. Clearly, these attributes of a disruption are all uncertain in nature. To combat with uncertain supply disruptions and to mitigate the impacts of supply shortages, many companies have adopted backup sourcing as the simplest and yet quite effective procurement strategy. The two selected sources – the major one and the backup one – are usually geographically dispersed so that a disruption at one place will not affect the other in order to ensure supply chain continuity. Both suppliers provide similar quality but may differ in terms of price, lead time, reliability, capacity, and other attributes. To this end, the decisions associated with how to work with the second supplier to ensure responsive supply under uncertain disruption risks have received a great deal of attention.

In order to reduce contingency purchasing cost and ensure responsive backup supply, buyers normally need to build a long-term relationship with the backup supplier. One way for doing so is to have a contractual agreement that allows the buyer to reserve capacity in advance. Capacity reservation, often observed in different industries such as electric power and semiconductor manufacturing (Kleindorfer & Wu, 2003), stipulates that the supplier prepares to provide the buyer with up to a predetermined quantity of the input item, and the buyer, depending on his current inventory level, may not use the entire reserved capacity (Serel, 2007). Such a purchasing strategy offers several benefits to supply chain members such as mitigating the "bull-whip effect", providing flexibility to handle uncertain demand, permitting better capacity and upstream procurement planning (Hazra & Mahadevan, 2009; Serel, Dada, & Moskowitz, 2001), and reducing operations cost.

We study such a strategic purchasing strategy adopted by buyers who mainly procure the modules from the major supplier with disruption risks, and the supply chain resilience is built through a long-term capacity reservation contract with a backup supplier. For the orders that have been reserved in advance, the backup supplier offers a discount when they are placed, while for the orders that have not been reserved, which are referred to as emergency order in the following analysis, the wholesale price is higher. As such, the buyer encounters a decision as to whether it would be

* Corresponding author.
E-mail addresses: penguinhj@163.com (J. Hou), azeng@wpi.edu (A.Z. Zeng), sunsuper@126.com (L. Sun).

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worthwhile to make a reservation at the backup source and how much to reserve. Meanwhile, the backup supplier needs to determine the unit reservation price in order to maximize its own total expected profit.

In addition, the contingent sourcing problem considered in this paper contains a minimum order quantity constraint (MOQ), which imposes that the contingent production level at the backup supplier, or the emergency order quantity from the buyer, must be greater than or equal to a minimum level M_0 (Hellion, Mangione, & Penz, 2014). MOQ is often used in industries such as pharmaceutical, apparel, consumer packaged goods, and chemical products, where companies enforce economies of scale due to high set-up costs associated with production or transportation processes (Porras & Dekker, 2006; Zhou, Zhao, & Katehakis, 2007). The MOQ policy is also quite common in China and other low-cost manufacturing countries (Zhu, Liu, & Chen, 2015). Our decision to consider MOQ requirement in this paper is largely motivated by our experience with a textile manufacturer in Jiangsu Province of China, which has a minimum production level of 3000 m of yarn per order. Every additional order from the same buyer has to be processed as a new order because additional raw materials need to be procured and machines have to be set up and started again. Therefore, for the second supplier who acts as a backup source in our model, the emergency order is viewed as a new order in addition to the reserved one and it has to meet MOQ to attain economies of scale in production process. In summary, the following research questions are addressed in this paper: (1) what are the players' optimal backup sourcing decisions and reservation price when disruption risk is uncertain and MOQ is required for emergency orders? (2) how do the changes in the major supply availability influence the terms of the contract? and (3) would lower MOQ level bring more benefits for both players?

The key contribution of this paper lies in the area that we develop a backup sourcing strategy through capacity reservation contract in the context of a supply chain with both disruption uncertainty and MOQ constraints. Such uncertainty risks and constraints are not only common in reality but also complicating the backup sourcing decision-making process. The paper is organized as follows. The related literature is reviewed briefly in the next section. Section 3 presents the expected profit functions of the buyer and the backup supplier and then derives their respective optimal decisions. Section 4 contains a set of numerical studies to assess the impacts of several key input parameters. Finally, Section 5 summarizes our work, discusses the model limitations and suggests future research directions.

2. Literature review

A large amount of research interest has emphasized various issues around backup sourcing under supply disruption risk and numerous results have been reported in the literature especially over the past decade. Existing literature suggests that a wide range of factors determine the decision-making configurations, which can lead to different action plans and desired outcomes. A combination of three major areas of environmental factors, namely disruption, buyer-supplier relationships, and availability or constraints of contingent delivery, often determines each decision-making environment. These environmental factors significantly complicate the decision-making process, as well as the associated modeling and analysis. Our study investigates the buyer's backup sourcing decisions under disruption uncertainty and capacity reservation contract as well as minimum emergency order quantity constraints. In what follows, the representative studies in backup sourcing under supply disruptions, capacity reservation contract and MOQ published in the past decade are briefly reviewed and discussed.

2.1. Backup sourcing under supply disruption risks

Sourcing can be used as a disruption-mitigation strategy in two ways: routine sourcing and contingent rerouting (Snyder et al., 2010). We focus on most recent examples of studies to summarize how backup sourcing is studied. Since the supplier profile determines how orders are allocated and affects the effectiveness of such strategy, we have noticed that the suppliers in recent studies are characterized by at least one of five factors. We give representative example studies of each case as follows.

(1) ***Reliability***. Quite often the concepts in probability theory, risk management and stochastic processes are used to model or capture a supplier's reliability. In a large number of studies of routing sourcing, the suppliers are supposed to be exposed to supply uncertainty or random disruptions (e.g., Sajadieh & Eshghi, 2009; Sawik, 2015; Xanthopoulos et al.; 2012). Perfectly reliable backup suppliers are also considered by many researchers, such as Yu, Zeng, and Zhao (2009) and Qi (2013), and some studies assume spot market as a contingent supplier that is totally reliable (e.g., Li, Wang, & Cheng, 2010). (2) ***Capacity or quality***. The work of Sawik (2011) deals with selecting a supply portfolio where the suppliers are assumed to have different levels of capacity limit, price and quality of offered parts; Lu, Huang, and Shen (2011) investigate product substitution and dual sourcing policies jointly when the reliable supplier has contingent production volume flexibility; Chen, Zhao, and Zhou (2012) study contingent sourcing from a backup supplier with higher cost and limited capacity; Xu, Zuo, and Liu (2015) compare the pricing flexibility and contingent sourcing from a backup supplier with infinite or random supply; Sting and Huchzermeier (2010) analyze how firms should contract with its backup supplier to install responsive capacity. (3) ***Information***. Although the majority of the research effort is devoted to examining supply chains under symmetric information, the work of Yang, Aydın, Babich, and Beil (2009) and Xu, Shi, Ma, and Lai (2010) study the sourcing decisions when suppliers have private reliability or cost information. (4) ***Relationship***. One stream of literature considers the competition among multiple suppliers, such as Babich, Burnetas A. N., and P. H. (2005) and Li et al. (2010). The other stream focuses on the cooperation between the buyer and the backup suppliers. For example, Hou, Zeng, and Zhao (2010) examine the backup contract between a buyer and its reliable backup supplier to mitigate supply disruptions; a recent example is given by Zeng and Yu (2015) that advocates a contractual partnership to ensure backup supply for a dual-sourcing model with three disruption levels (major, moderate, and minor), finite supply capacity, and random market demand.

In this paper we restrict our attention to a supply chain that consists of one buyer and two suppliers: one major supplier that is prone to uncertain disruption risk and the other is the backup supplier. The backup supplier is activated only when the major supplier's delivery cannot satisfy the demand. The relationship with the backup supplier is maintained through capacity reservation. We attempt to bridge the gap in disruption management by investigating the buying firm's optimal purchasing decisions when certain elements of the suppliers related to the three factors are present, namely disruption uncertainty, flexible backup capacity but with MOQ constraint, and long-term relationship through capacity reservation contract.

2.2. Capacity reservation

The practice of capacity reservation has been widely studied as a vehicle for mitigating various supply chain risks and strengthening buyer-supplier relationships (Serel et al., 2001). In the research of capacity reservation with one supplier, Jin and Wu (2007) study an one-manufacturer-multiple-customer capacity reservation

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