Computers and Operations Research 000 (2016) 1–13

Contents lists available at ScienceDirect

Computers and Operations Research

journal homepage: www.elsevier.com/locate/cor

On the loss-averse dual-sourcing problem under supply disruption

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ARTICLE INFO

Article history:
Received 2 February 2016
Revised 11 September 2016
Accepted 12 December 2016
Available online xxx

Keywords:
Loss aversion
Supply disruption
Dual sourcing
Stochastic programming

ABSTRACT

Supply disruption is a common phenomenon in industry, and loss-aversion has been recognized as an inherent behavior for decision makers. This paper combines these two factors by considering a loss-averse firm facing a random demand and sourcing from two suppliers. One supplier is cheaper but subject to potential disruption possibility, while the other one is reliable but more expensive to purchase from. We establish a stochastic programming to maximize the expected utility under loss-aversion criterion, and characterize the optimal solutions of the order quantities submitted to the two suppliers. It is found that the unreliable supplier is always used with positive order quantity due to its economical advantage, while the reliable supplier can be useless under some condition. We conduct computational experiments which illustrate that the optimal order quantity from the unreliable supplier, as a main supply source, may manifest a distortion from that under risk neutrality. In addition, we investigate the scenario of sequential ordering and formulate the problem as a two-step stochastic dynamic programming. We prove that the order strategy in this scenario can be characterized by two single-sourcing optimal order points, and provide numerical results on parameter sensitivities of the value of flexibility given by the sequential ordering opportunity.

1. Introduction

Management on supply disruption has grown in importance due to the need for designing, operating, and coordinating supply chains. The supply disruption can be the consequence of a host of unintended events and cause severe damage to supply chain firms [42]. A well-known example is the experience of Ericsson Corp., which suffers from a catastrophic shortage of components and the resulting $400 million in lost sales due to a fire shutting down its supplier, Philips Semiconductor plant in Albuquerque, New Mexico, for six weeks. Hence, many firms adopt a multiple sourcing strategy as a tool to hedge against supply disruption and to safe guard their sourcing systems [29]. For example, Nokia, which also relies on Philips as a main supplier, adopts other soucing channels shortly after the fire accident to ensure a relatively steady supply for its components. Up till now, the advantage of such a backup supplier to mitigate supply risk has been well acknowledged, with the corresponding dual sourcing strategy widely employed in many industries, such as the aircraft [26], pharmaceutical [13], and electronics [34] and [14] industries.

On the other hand, the attitude facing such supply risk is crucial in making related sourcing decision. In many similar supply chain management problems, sourcing decisions associated with risk consideration is usually evaluated under the objective of maximizing expected profit (see *e.g.* [25] and [41]. Despite being computationally tractable and easy to estimate, it has been observed that the use of this expected measure may lack precision in characterizing the objective of decision maker [16] and [4]. In late 1970s, Kahneman and Tversky [17] find people's tendency to strongly prefer avoiding losses to acquiring same-sized gains and refer it as to a loss-averse behavior among decision makers. An example of loss-aversion behavior is that one who is penalized of $100 due to carelessness in work will lose more satisfaction than the gained satisfaction from a $100 windfall of hard work reward. This phenomenon has been convincingly demonstrated in finance, economics, marketing, and organizational behavior. Hence, properly quantifying loss aversion behavior becomes crucial for decision makers in business because being conservative towards loss, for the survival of many companies in today's more variant business world. Especially, it is of significance to explore how the degree of loss aversion affects the optimal decisions in supply chain operations with disruption factors in both supply and demand, which is oversimplified to be addressed using solely the "expected-measure-of-risk".

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http://dx.doi.org/10.1016/j.cor.2016.12.011
0305-0548/

In this paper, we establish a stochastic modeling framework which combines the issues of supply disruption, dual sourcing and loss aversion, to explore how the utility is manifested for a loss-averse firm and what ordering strategy should be adopted. We assume that the firm orders from two suppliers: Supplier 1 is cheaper but unreliable with some probability of disruption, while Supplier 2 is reliable but more expensive. The disruption is modeled as an "all-or-nothing" type, *i.e.*, once the disruption occurs, no unit of the order can be delivered from Supplier 1 to the firm. This corresponds to the consequence of disruption event including both internal accident such as machine breakdown and exogenous force such as strike, nature disaster, political incident, *etc.* The demand side is a newsvendor type of stochastic demand with a known distribution. The optimal order quantities from the two suppliers are characterized to maximize the expected utility for under loss aversion. The scenarios of both simultaneous ordering and sequential ordering are investigated, respectively. We conduct both theoretical analysis and numerical experiment, seeking to answer the following questions: How does the behavior of loss aversion affect the firm's supply disruption management and the corresponding sourcing strategy? Between the two sources, which one is used as a main supplier? On what condition should a single-sourcing policy be adopted? What is the relationship between the optimal ordering decisions under the scenarios of simultaneous ordering and sequential ordering, and how is the value of flexibility provided by the sequential ordering manifested?

From the perspective of theoretical research, this paper focuses on supply disruption under a dual sourcing environment. Traditionally, most literature on supply uncertainty investigates the problems in the presence of a single supplier. Nevertheless, some more recent papers have involved dual sourcing strategy with supply disruption. For example, Babich [1] explores a firm sourcing from competing risky suppliers and shows how the default risk and default co-dependence of the supplier affect the firm's procurement and production decisions.Babich et al. [2] investigate the issues of interaction of competition and diversification under supplier default risk with binary outcomes.Tomlin [34] focuses on disruption risk mitigation mechanisms under dual sourcing, in which one supplier is unreliable and the other one is reliable with volume flexibility.Wang et al. [39] establish a two-stage stochastic programming to study the effects of supply risk mitigation strategies and compare the strategic choice between process improvement and dual sourcing. Tang and Kouvelis [33] investigate the value of dual sourcing compared to sole sourcing under competition between two manufacturers who can source from one or two unreliable suppliers with random yield. Qin and Rao [26] consider a supply chain with two heterogeneous suppliers in competition and examine the impact of supply capacity risk on the supply chain decisions and profits. Lawrence et al. [20] provide a comprehensive review of operations management models for the stream of research on supply chain disruptions. In contrast to the above study based on traditional risk-neutral criterion, our paper focuses on the optimal sourcing strategies for a loss-averse decision maker.

On the other hand, this paper belongs to the category of risk-based procurement optimization problems from the methodological point of view. The risk-neutral criterion which aims at expected profit maximization has been criticized for a long time due to many counter examples observed in reality, and alternative risk analysis models on supply chain management have been proposed. The most commonly used risk models are listed as follows with sample papers.

- Von Neumann-Morgenstern Utility Functions: Keren and Pliskin [18], Lau [19], Wang et al. [38] and Choi and Ruszczynski [12] investigate the newsvendor problem under the risk-averse optimization objective of a concave von Neumann-Morgenstern utility function.
- Profit Target Probability Measures: Lau [19] and the successive works such as Parlar and Weng [24], Sankarasubramanian et al. [27], and Shi and Chen [31] inv estigate the inventory optimization problem with the goal of maximizing the probability to achieve a certain predetermined profit level.
- Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) Objectives: This approach is originated from finance and then applied to inventory optimization problems by Cheng et al. [6], Gotoh and Takano [15], Özler et al. [23], and Chiu and Choi [7], among the others.
- Mean-Variance Analysis: This approach is also originated from finance (pioneered by Nobel laureate Professor Harry Markowitz in the 1950s) and then applied to inventory optimization problems by Chen and Federgruen [5], Wu et al. [40] and Choi and Chow [8], Choi et al. [9], [10]], Choi and Chiu [11], among the others.

Besides the above risk-aversion models, the loss-aversion behavior is more closely related to this paper and has attracted attentions from academy. As a pioneer work, Schweitzer and Cachon [28] shows that a loss-averse newsvendor will order less than a risk-neutral one.Wang and Webster [36] extend the model into the case of positive shortage cost and show that this downward distortion for order quantity decision may not apply. Wang and Webster [37] investigate the supply chain model in which a risk-neutral manufacturer sells through a loss-averse retailer to the final market. Wang [35] and Liu et al. [22] further extend the problem into a game setting of multiple loss-averse newsvendors competing with each other, and provide equilibrium results under various demand allocation rules. Shen et al. [30] study a supply chain problem in which a loss-averse manufacturer purchases component from a retailer and a backup procurement option. Li and Li [21] study an optimization problem for a random yield production system under loss aversion with both multiplicative and additive random yield risks. This paper differs from the above as we consider supply disruption under a dual-sourcing environment, which complicates the stochastic programming as follows: (a) We have two ordering decision variables, both with constraints; (b) We have two types of random factors in demand side and supply side, respectively; (c) We consider a static optimization problem and a dynamic stochastic programming problem as well, and make comparison between these two. Table 1 lists the risk models mentioned above and positions our paper in literature.

The rest of paper is organized as follows. In Section 2 we decribe the model. In Section 3 we derive the optimal ordering decisions for two suppliers for the problem. In Section 4 we conduct computational experiments to show the sensitivity of the order quantities to the loss-aversion degree and other system parameters. In Section 5 we establish a two-step stochastic dynamic programming to analyze the problem of sequential ordering, and highlight the value of flexibility given by the postponed ordering opportunity. Section 6 concludes the paper with future research directions.

2. Model description

Consider that a firm orders from two suppliers to satisfy a random demand D. Supplier 1 is subject to a random disruption, under which no unit of the order can be delivered to the firm. Such a supply uncertainty is usually called as an "all-or-nothing" type of disruption. The probability of the disruption occurrence is $\alpha \in$

Please cite this article as: X. Li, Y. Li, On the loss-averse dual-sourcing problem under supply disruption, Computers and Operations Research (2016), http://dx.doi.org/10.1016/j.cor.2016.12.011