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Value of information through options contract under disruption risk

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ABSTRACT

In this study, we consider the replenishment strategy of a buyer with two suppliers. Since its regular supplier is prone to disruptions, the buyer utilizes an options contract with a more expensive but perfectly reliable supply option. We introduce three models depending on the level of information available when the options from the reliable supplier are exercised: (i) Full information (both supply and demand information), (ii) partial information (only supply information), and (iii) no information. We derive the optimal replenishment strategy of the buyer in each of these models and characterize the conditions under which the reliable supplier is utilized. Through both analytical and numerical studies, we investigate the effectiveness of an options contract under different levels of information.

1. Introduction

In this paper, we focus on the effectiveness of a dual sourcing strategy in the presence of supply disruption risk under various levels of information. Disruptions are random events that cause a supplier to completely stop deliveries. That is, supply disruption risk is a discrete form of supply uncertainty. The consequences of supply disruption can be severe if companies do not have effective mitigation strategies. For instance, Tomlin and Snyder (2007) report from Wall Journal that a three-week strike caused Harley-Davidson to announce less shipments and decreased earnings per share. Another example is the fire at a semiconductor plant in March 2000 which caused over $400 million dollars to Ericsson since the company did not have alternative sourcing options whereas Nokia suffered little as it was able to increase production in alternative suppliers (Latour, 2001). A similar situation occurred for Toyota when a fire destroyed the factory of the brake valve supplier in 1997 (Reitman, 1997). Another example is Hurricane Mitch in 1998 that affected banana supply fields in Central America. In response, Chiquita managed to increase production at other suppliers whereas Dole faced declined revenues due to lost supply (Griffy-Brown, 2003). Companies can also utilize demand management tools to cope with supply disruptions as Dell did during the earthquake in Taiwan in 1999 (Griffy-Brown, 2003).

Tomlin (2006) classifies tactics against supply disruptions into two major categories: (i) mitigation strategies such as inventory and multiple sourcing where action is taken before disruption, and (ii) contingency tactics such as rerouting and demand management. Snyder et al. (2016) provide an extensive review of mathematical models for these strategies. Sourcing from multiple suppliers has been widely used in industry (Nokia and Chiquita examples provided above) and investigated in the literature (please see the discussion in Section 2). Zeng and Xia (2015) report that Staples uses a dual sourcing strategy where one of the suppliers is called upon for extra capacity when the other is disrupted. Another example by Zeng and Xia (2015) is GE Aviation uses its supplier in Long Island as a backup source that is compensated by a premium. Such backup agreements are reported to be widely used in automotive, pharmaceutical and electronics industries (Sting & Huchzermeier, 2010). A particular form of sourcing from multiple suppliers is to reserve capacity from a reliable supplier in order to hedge against supply risks, which is also the main focus of our work. Such capacity reservation (or options as we use it) agreements are observed in different industries such as textile (Eppen & Iyer, 1997), telecommunications (Erkoc & Wu, 2005), and semiconductor (Barnes-Schuster, Bassok, & Anupindi, 2002; Jin & Wu, 2007).

Although widely used in practice as a mitigating strategy against uncertainty, there are a few studies in the literature that propose and investigate options (or capacity reservation) contracts to cope with disruption risk (see, for instance, Chopra, Reinhardt, & Mohan, 2007; Saghafian & Van Oyen, 2012). In this study, we aim to contribute the literature by investigating the benefits of an options contract under supply disruption risk and demand uncertainty. Namely, we characterize the value of a reliable supplier under different levels of uncertainty. For this purpose, we consider a buyer that sells a single product to the end market in a single

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period. Due to the disruption risk at the regular supplier, the buyer opts to sign an options contract with a reliable supplier. The order quantity from the regular supplier and the reservation quantity from the reliable supplier are determined at the beginning of the period, before any information is available about supply and demand conditions. We consider three models depending on the level of information that the buyer possesses when it determines the number of options to exercise. In the full information model, the uncertainties in supply (whether disruption occurred or not) and demand resolve before the buyer determines the number of options to exercise. Hence, ordering from the reliable supplier mitigates both the supply and demand risks. In the partial information model, only supply uncertainty resolves; hence, the options are to be exercised under demand uncertainty. That is, the options can be used only against disruption risk. In the no information model, the contract with the reliable supplier boils down to a wholesale-price-only contract as the options are exercised with no information on demand or supply. We thoroughly study these models in order to understand the effects of information level on the effectiveness of the options contract. We derive the optimal order and reservation quantities, and characterize settings where the reliable supplier is not utilized, and where information does not provide additional benefits. Our major observations can be summarized as follows.

- If the total cost of item from the reliable supplier is low enough (or disruption probability is high enough), the reliable supplier is utilized even in the no information case.
- There are problem settings where the options contract is not utilized even with full information.
- When utilized with full information, reliable supplier is used as a primary supply option rather than a backup option for disruption.
- When options are purchased to be utilized with disruption information only, they are used as a backup option (that is, they are exercised only under disruption) when the exercise cost is larger than the unit cost of the unreliable supplier. If exercise cost is lower, the reliable supplier is used as a primary source and the order from the unreliable supplier decreases.
- When the options are to be exercised only with supply information, if the option exercise cost is less than the unit cost of the unreliable supplier, all purchased options are utilized regardless of the disruption. Hence, the flexibility of options does not provide additional benefits to the buyer.

We also perform numerical analysis to illustrate our findings and quantify the benefits of making option-exercise decision with demand and supply information. Our computational analysis indicate that disruption information alone can improve the expected profit of the buyer by as large as 17% while the impact might be as high as 23% when it is also coupled with demand information.

The rest of the study is organized as follows. Section 2 discusses the related literature. The mathematical models are presented and analyzed in Section 3. Section 4 presents a thorough computational analysis. We conclude in Section 5 summarizing our major findings and offering further research directions.

2. Literature review

Our work contributes to the important and growing research area of supply disruption management. We employ a dual sourcing mitigation strategy with options contract to deal with the risk of disruption. Our review of the literature starts with the studies that consider a single, unreliable supplier. We continue with routine sourcing papers where the buyer places firm orders to multiple suppliers. Studies that involve contingent rerouting papers are discussed next. We also pay attention to studies that consider the value of information in this context. Snyder et al. (2016) provide a detailed review for supply chain models with disruptions.

Early work on supply uncertainty usually considers single-supplier systems. Bielecki and Kumar (1988) show that zero-inventory policies are optimal under certain settings when there is supply uncertainty. Parlar and Berkin (1991) introduce disruption in an EOQ environment. Berk and Arreola-Risa (1994) point out inaccuracies in Parlar and Berkin's original model and offer a corrected model. Parlar and Perry (1995) extend it to include the reorder level into the model. Gürler and Parlar (1997) also consider an EOQ environment. They study a two-supplier setting where the suppliers are either on or off with random durations. Moinzadeh and Aggarwal (1997) consider the finite production rate extension and propose an (s, S) type policy. Yano and Lee (1995) provide a review of quantitative models for lot sizing when yield is random. Gupta (1996) analyzes a continuous review system with lost sales. The unreliable supplier is ON or OFF for exponential durations and demand is generated by a homogeneous Poisson process. Parlar (1997) considers a similar setting where the supplier availability is modeled as a semi-Markov process. In a similar environment, Arreola-Risa and DeCroix (1998) considers partial backordering.

There is also a growing body of literature that uses routine sourcing as a strategy to mitigate disruption risk. In routine sourcing, the buyer orders from multiple suppliers at the beginning and has no chance to update its orders depending on the realized supply conditions. Anupindi and Akella (1993) study dual sourcing in a multi-period environment. They argue that the buyer never orders from the expensive supplier alone. Swaminathan and Shanthikumar (1999) consider a similar setting and show that the buyer may choose to order from the expensive supplier only if the demand follows a discrete distribution. Iakovou, Vlachos, and Xanthopoulos (2010) consider a single period setting where a buyer orders from two unreliable supplier. Xanthopoulos, Vlachos, and Iakovou (2012) also consider two unreliable suppliers. They develop models for both risk-neutral and risk-averse decision makers. Dada, Petruzzi, and Schwarz (2007) consider a single period model with multiple unreliable suppliers and the objective is to choose the suppliers to order from and the corresponding order quantities. They argue that if a supplier is chosen, then cheaper suppliers will also be chosen whatever their reliability degrees are. That is, cost overrides reliability. Federgruen and Yang (2008) and Federgruen and Yang (2009) also consider similar problems. Other studies that involve selecting among a set of unreliable suppliers include Berger, Gerstenfeld, and Zeng (2004), Ruiz-Torres and Mahmoodi (2007) and Tehrani, Xu, Kumara, and Li (2011).

We continue with studies that consider contingent strategies against disruption risk. Tomlin (2006) studies an infinite-horizon, periodic-review inventory system where a single firm replenishes from two capacitated suppliers, one of which is prone to disruption. He shows that in the special case where the reliable supplier has no volume flexibility and the unreliable supplier has infinite capacity, the firm will follow a single strategy: carrying inventory, single-sourcing from the reliable supplier or passive acceptance. It is argued that contingent rerouting is an option when the reliable supplier has volume flexibility. Chen, Zhao, and Zhou (2012) also consider a periodic-review inventory system with two suppliers one of which is unreliable. The reliable (backup) supplier charges a fixed cost as well as a more expensive unit cost. Chopra et al. (2007) study a single-period model with deterministic demand where one supplier is subject to both yield and disruption uncertainties and the other is perfectly reliable. In contrast to Tomlin (2006), both yield and disruption uncertainties are unresolved when the buyer places an order to the first supplier. They also require the buyer to reserve from the reliable supplier at a given