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Dynamic replenishment from two sources with different yields, costs, and leadtimes

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ABSTRACT

We study a single-item periodic-review inventory system with two sources of supply: in-house production and outsourcing. The two sources differ in yields, costs, and leadtimes. Demands in consecutive periods are independent random variables and stockout is fully backlogged. Our problem is to characterize the optimal dynamic policy that simultaneously determines the in-house production quantity and the outsourcing quantity for each period to minimize the total discounted cost. We show that the optimal policy for in-house production can be characterized by a threshold and the production quantity is decreasing in the starting inventory. The optimal outsourcing policy, however, is more complex, and a threshold-type policy is only optimal under a more restrictive assumption about the yields. Comparative statics about the effects of yield uncertainty, outsourcing on the optimal policy, and cost performance are discussed.

1. Introduction

In this paper, we address the problem of simultaneously determining inventory replenishment strategies from two sources with different leadtimes, yields and costs. The importance of the sourcing strategy has been emphasized by Erickson et al. (1995) in The Purchasing Handbook: “Supplier selection is the most important milestone in the purchasing process. The ultimate success of a new product, the profitability of a product line, and the timeliness of delivery to the marketplace may depend on this decision”. As Johnson (2006) also points out, it is quite common for a manufacturer or distributor to have different supply sources that have different grades of reliability in terms of the quantity and quality of orders delivered. When faced with this situation, it is imperative that replenishment decisions take into account supply uncertainty and related cost implications. Particularly, a company may need to protect itself from the uncertainty by having diversified suppliers. Indeed, after the fiasco of the UPS strike in the United States two years ago, most companies vowed that they would never ever use a single supplier again. Waart (2006) reports a case of Hewlett–Packard (HP). In 2000, HP was unable to obtain sufficient volumes of flash memory cards. Consequently, the company was unable to ship about 2,500,000 printers. Subsequently, HP took a dual-sourcing strategy, which resulted in annual procurement savings of more than 100 million by better managing supply and demand risk. A more recent example is Apple Computer, which uses Motorola as a unique chip supply source for its very popular G4 model. Currently, Apple is suffering losses as a result of Motorola's inability to supply enough chips. By implementing dual-sourcing, GM has reduced its vehicle development cycle time from four years to 18 months (Gutmann, 2003). Airbus, reported by Wiesmann (2007), has ceded design and production of parts of its planned A350 aircraft to Russia's United Aircraft Corporation as flag-carrier Aeroflot firmed up an order for 22 of the wide-body jets. In other words, the aircraft maker's outsource strategy can secure orders despite fierce competition from US rival Boeing.

The above situations indicate that dual sourcing offers a solution for reducing the risk in the procurement process and closely matching supply with demand. However, how do companies find an effective way of deciding how to source, when and from whom? That is the key issue that our paper addresses. To the best of our knowledge, our paper is the first to consider the combined impacts of leadtimes, yields and costs for achieving an effective dual sourcing strategy. We assume that an original equipment manufacturer can order a critical material or component from two sources: in-house production and outsourcing. Such sourcing practices are popular in various North American industries, such as electronic appliances, automobile and toy.

We assume that in-house production has no leadtime while outsourcing has an one-period leadtime. The reason is that due to the geographical distance, the leadtime of outsourcing is usually quite long compared with the leadtime of in-house production. Moreover, this assumption is commonly used in the literature of dual sourcing, such as Anupindi and Akella (1993), in order to achieve the analytical tractability. Moreover, the variable costs of

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these two sources may be different. Next, we assume that the replenishment yield from in-house production is uncertain while the replenishment from outsourcing is certain. When the firm produces the material in his or her own factory, the production yield is uncertain due to the in-house operations, so that the quantity received from a replenishment is also uncertain (see Henig and Gerchak, 1990). Another case is that the domestic supplier has a finite capacity and receives multiple orders in each period (the firm's order is one of these orders and the number of orders may change from time to time). As a result, the firm's order from the domestic supplier can be modelled as an uncertain portion of the total amount produced by the domestic supplier in each period. The firm can apply a selective sourcing strategy to safeguard the quality of the manufacturing process at the overseas supplier's factory. For example, when products are being manufactured, a selective sourcing quality engineer is present to insure that the product is being made to the proper standards and quality level (see McNeill et al., 2005). Another suitable case is that the firm can select the overseas supplier through a third party, such as ONet (http://www.outsourcingnetwork.net), who will guarantee the quality of the product on behalf of the firm. Therefore, it is reasonable to assume that the replenishment from the overseas supplier is with certain yield.

The objective of this paper is to characterize the optimal dynamic policy that simultaneously determines the order quantities from two sources to minimize the total discounted cost. We show that the optimal replenishment policy from in-house production is of a threshold type, i.e., it is optimal to order if and only if the starting inventory in a period is below a threshold value. The optimal order quantity from in-house production decreases in the starting inventory. The optimal policy from outsourcing is more complex, and a threshold-type policy is optimal under a more restrictive assumption about the yields. To understand the implication of dual sourcing and random yields, we compare our model with two existing models in the literature: one includes dual sourcing but not uncertain yield; the other includes uncertain yields but only has one supply source. Comparing to the first model, we prove that the threshold of replenishment from in-house production with uncertain yield is higher than that with certain yield. In addition, we demonstrate that the suppliers' variable costs cannot dominate the decision of the choice of sourcing when the yield is uncertain; the optimal order quantity may not be monotone in yield variability; the yield variability deteriorates the cost performance. Next, by comparison with the second model, we find that although the dual-sourcing strategy can achieve a significant cost saving under both supply and demand uncertainties, the percentage cost saving becomes small when either supply or demand uncertainty becomes high. The contribution of this study is twofold. First, we analytically characterize the structure of optimal replenishment policies for the dual-sourcing model with different yields, costs, and leadtimes. Second, we develop fundamental insights about the impact of dual sourcing and yield uncertainty by comparison of the previous literature.

Our paper is closely related to two streams of research: lot sizing with random yields and replenishment from multiple suppliers or multiple delivery modes.

Research on lot sizing with random yields has been initialized by Karlin (1958) and received a lot of attention in operations research. Much work has been done on periodic-review and/or multistage models in dynamic settings, including Henig and Gerchak (1990), Parlar and Wang (1993), Wang and Gerchak (1996), and Chen et al. (2001). The focus of these papers is on the structure of the optimal policy. Yano and Lee (1995) provide a comprehensive review of research before 1995 in this area. The issues recently addressed related to uncertain yields are quite diverse, including for example, dynamic pricing under uncertain yield (Li and Zheng, 2006), applications in agricultural and food businesses (Kazaz, 2004), diversification (Tomlin and Wang, 2005; Dada et al., 2007; Chopra et al., 2007), and the impact of yield improvement on expected profits (Gupta and Cooper, 2005). Recently, Xu (2010) analyzes a decentralised supply chain comprised of a supplier and a manufacturer with random yield. The author finds that both the supplier and the manufacturer could gain a high expected profit under an optional contract. Tang et al. (2012) study a dynamic pricing strategy for the newsvendor problem with random yield. The authors characterize the optimal price and ordering decisions and compare the profit performances with dynamic and fixed pricing policies. They find that such a dynamic policy can result in a high benefit when demand uncertainty is low. Wang et al. (2014) considers a periodic-review model with random yield, disruption, and limited inventory capacity. Under the assumptions of an additive random yield and a linear production cost, the authors find that an order-up-to policy is optimal.

There is also an extensive literature related to either multiple suppliers or multiple delivery modes. Fukuda (1964) is the first to consider an inventory model with two delivery modes. The lead times of the two modes vary by exactly one period and the faster one is more expensive. The optimal policy is shown to have the following form. There are two base-stock levels. If the initial stock level is below the smaller base stock level, then an order with the faster mode is placed to bring the stock level back up to that base-stock level. No order with the faster mode is placed otherwise. The system stock level is then brought up to the larger base stock level by ordering with the slower mode. Whittemore and Saunders (1977) first analyze a two-supply-option model where the difference of delivery time can be more than one period. Anupindi and Akella (1993) study three different models with two uncertain suppliers. Different from our model, the authors do not simultaneously integrate the impact of leadtimes and yields into one model. Güllü et al. (1999) consider a single supplier with supply uncertainty. The supply availability is three categories: unavailable, partially available, and fully available. The authors find that an order-up-to policy is optimal. Mohebbi (2004) examines a continuous review of a single supplier with random lead time and disruption. Feng et al. (2006) show that when the number of modes is more than two, only the fastest two modes have optimal base stocks. Veeraraghavan and Scheller-Wolf (2008) extend the literature by allowing the difference between the lead times of the two modes to be more than one. Wang et al. (2010) investigate whether a buying firm should do multiple sourcing and/or improve supplier reliability. Li et al. (2009) and Zhu (2012) consider the use of expediting orders as an additional source in response to demand uncertainties. Note that none of the above mentioned papers consider the impact of uncertain yield. Giri (2011) studies a single-period dual-source model under yield uncertainty and risk aversion. Recently, Kouvelis and Li (2013) study how to use an emergency sourcing as contingent action after the yield uncertainty of the regular cycle order is realized. The authors explore the impact of yield and demand uncertainty on the cycle order size, the emergency order size, and the way to split the available good units between the fast and slow shipping modes. Ahiska et al. (2013) investigate a dual-source model with one reliable supplier and one unreliable supplier. The unreliable supplier status is controlled by a two-state Markov process. But, there is no lead time difference between two suppliers. Through numerical experimentation, the authors determine the structure of the optimal ordering policy. Riezebos and Zhu (2015) generalize theory on material requirements planning ordering by including the occurrence of dynamic lead-time variation and order crossovers in a multiple-supplier environment.

We end this section by describing the organization of the paper. In Section 2, we introduce the notation, our assumptions, and some properties of the one-period profit function. In Section 3, we formulate the finite-period problem with Markov decision programming and explore various structural properties of the optimal policies.