Int. J. Production Economics 157 (2014) 238–249

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Optimal policy structure characterization for a two-period dual-sourcing inventory control model with forecast updating

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ARTICLE INFO

Article history:
Received 1 October 2012
Accepted 25 July 2014
Available online 22 August 2014

Keywords:
Inventory control
Forecast updating
Dual supply
Short life-cycle products
Optimal solution

ABSTRACT

A proposed single-product, stochastic, two-period inventory control model combines demand forecast updating with the flexibility of two supply sources. Demand is modeled by two independent, random variables over a two-period selling season. At the beginning of the first period, two quantities are ordered using two different supply options: a local supplier who delivers the ordered quantity immediately and a second supplier who delivers the ordered quantity at the beginning of the second period. The local supplier charges a higher cost per ordered unit. The model considers an initial inventory, so the decision maker has an opportunity at the beginning of the first period to return part of the available inventory to the supplier (or sell it in a parallel market). At the end of the first period, any unsatisfied demand is backlogged to be satisfied in the next period. At the beginning of the second period, exogenous market information updates the second-period demand forecast. According to this updated forecast and the actual inventory level, an additional quantity is ordered using the local procurement source or another quantity is returned to the supplier (or sold in a parallel market). With a dynamic programming approach, this research exhibits the structure of the optimal policy, characterized by order-up-to and salvage-up-to levels. The findings provide the structure of the second-period conditional optimal policy and analytical insights that characterize the first-period optimal policy. Furthermore, a numerical study reveals the impact of information quality on the optimal policy and the trade-off between the two procurement options.

1. Introduction

We study short life cycle products for which demand occurs during a short selling season. The basic inventory management model that fits this type of situation is the well-known *Newsvendor* model in which a decision maker orders a single quantity to fulfill uncertain single-period demand. At the end of the period, unsatisfied demands are lost (maybe inducing a penalty shortage cost), and remaining inventory is salvaged at a salvage value. Vast research considers the *Newsvendor* models (for a review, see Khouja, 1999) and proposes extensions to improve this model. A key extension is the two-period setting, which allows decision makers to react to the level of demand. Understocking and/or overstocking is costly, so in a stochastic setting, decision makers must use forecasts of future demand to minimize such costs. In some cases, it is possible to improve the quality of these forecasts during the decision process, such as by using information technology-enabled sales or market data. Between successive decisions, new information provides updates to the demand forecast for the remaining of the planning horizon. This new information may take two forms: endogenous, such as actual demand for the same product in previous periods, or exogenous, such as sales of a preseason product. We focus on the effective use of exogenous information. Tan et al. (2007) suggest ways to improve demand forecasts using exogenous information. For example, if a company uses sales representatives to market its products, the information collected from the distribution of sales vouchers or quotations, which suggest that customers are interested in buying, can update demand forecasts. In Internet retailing, the number of visits to a commercial website indicates the level of interest in some of the offered products; a precise visit to a certain subpage could indicate the interest of the buyer by a specific product. Furthermore, the company can ask online visitors to complete "wish lists" that indicate products

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http://dx.doi.org/10.1016/j.ijpe.2014.07.028
0925-5273/

that interest them and that they would be willing to buy if they had the funding or enough time. Moreover, incomplete shopping carts can provide information about the willingness of customers to complete the purchase of a specific commodity in the future. We propose a model that integrates these forms of information and uses a dual sourcing framework. With this framework, the decision maker can order twice for the second period: from a fast (local) supplier with zero delivery lead time and from a slow (distant) supplier with a one-period delivery lead time. Between the two ordering decisions, the decision maker observes actual demand in the first period and market-collected information. Previous studies investigate the impact of production capacity constraints on the choice between slow (low-cost) and fast (high-cost) procurement sources (Cheaitou et al., 2009); we explore here the impact of forecast quality on the trade-off between different procurement strategies. Our main focus is on the choice between a low-cost option using a fuzzy forecast for the second period demand (i.e., decision made before collecting exogenous information) and a high-cost option using better quality forecasts (i.e., decision made after observing exogenous information and updating forecasts for second period demand). The originality of our model stems from two features. First, we use different decision variables that allow a retailer to sell part of the available inventory to a parallel market or return them to the supplier at the beginning of each period. These decision variables can be especially useful after updates to the demand forecasts of the second period. Second, we provide a complete characterization of the structure of the optimal policy and we show that it is a threshold type order-up-to policy. In the next section, we review pertinent literature, which leads us to present our proposed model and define the corresponding optimization problem. In the next section, we define the optimization method used to solve our optimization problem, then detail the numerical study we conducted, which revealed the properties of the main model parameters and their impact on the optimal policy. We conclude in the last section.

2. Related literature

Our work sits at the intersection of two research streams: two-period inventory models and inventory models with dual sourcing. Several authors have investigated two-period inventory control models. The published works in this area can be classified into two sub-categories. The first sub-category deals with models without forecast updates. Hillier and Lieberman (2001) analyze a two-period model with uniformly distributed independent demands. Their model has been solved using a dynamic programming approach, and a closed-form solution has been obtained under some simplifying assumptions. Lau and Lau (1997, 1998) develop lost sales two-period models numerically solved via a dynamic programming formulation. Cheaitou et al. (2009) propose a two-period production planning and inventory management model without forecasts updates. In our paper, we develop an extension to Cheaitou et al. (2009) model in which we introduce a forecast updating process and we focus on the characterization of the optimal policy within a general framework instead of solving special cases or obtaining numerical solutions. The second sub-category studies two-period models with demand forecast updates. In general, the use of information updates to improve demand forecasts for inventory management has been investigated since the 1950s (Scarf, 1959; Murray and Silver, 1966; Azoury, 1985; Lovejoy, 1990). In particular, Gurnani and Tang (1999) consider a two-period model with no demand at the first period. At the end of the first period, and after a first procurement decision, exogenous information is collected, permitting to update the initial forecast for the second period demand. They consider a case in which the value of the information observed between the first and second decision periods varies from worthless to perfect. In their model, the unit ordering cost at the second decision period is uncertain and could be higher or lower than the unit ordering cost at the first decision period. Choi et al. (2003) propose a quite similar two-period model with an update of the forecast of the second-period demand via some market information. Donohue's (2000) two-period contract model aims to determine efficient wholesale price and return policy decisions with single-demand period and exogenous information updating processes. The aim of that model is to ensure coordination between the manufacturer and the distributor.

Another class of demand forecast updating processes exists in which the demand of the second period is correlated with the demand of the first period. Many of the studies of this category were motivated by the quick response policy in the apparel industry (Fisher et al., 1994; Choi et al., 2006). For instance, in the model proposed by Fisher and Raman (1996), the demand of the whole horizon and the demand of the first period are characterized via a joint probability density function. Furthermore, the order size for the second period is constrained by a limited amount. The optimal policy is numerically approximated via some efficient heuristics. Tan et al. (2009) use advance demand information to solve an inventory problem with two demand classes. Bradford and Sugrue (1990) use a Bayesian process to update the second period demand forecast after having observed the value of the first period demand. In Ma et al.'s (2012) proposed model, the retailer has two ordering opportunities before demand is realized, and information updating is considered. They also classify research into inventory management models with demand forecast updates in three categories. It is worth noting that the forecast updating processes are widely used in the context of supply contracts (see Bassok and Anupindi, 1995; Barnes-Schuster et al., 2002; Eppen and Iyer, 1997; Tsay, 1999; Brown, 1999).

The demand forecast updating process used in our paper considers an external information to update the second period demand forecast and assumes that first and second periods' demands are independent. It is therefore similar to those used by Gurnani and Tang (1999), Choi et al. (2003), and Donohue (2000).

The dual sourcing question was first addressed in pioneering work (Daniel, 1963) that focused on emergency shipments limited to two modes. Fukuda (1964) extends this analysis to feature unbound emergency shipments and general lead time values. Whittemore and Saunders (1977) consider a general model with arbitrary lead times and identify cases in which it is optimal to use only one supply mode. Moinzadeh and Nahmias (1988) examine the basic dual supply problem in a continuous review setting. Zhang's (1995) period review system includes up to three supply modes. Lawson (1995) has considered a specific form of lead-time flexibility that is formally modeled as a series of expedite and de-expedite opportunities. More recently, Li et al. (2009) propose a model with two procurement opportunities: the first, placed at the start of the preseason and received at the beginning of the selling season, and the second one, placed at or after the beginning of the selling season and received after a delivery lead time. A third decision variable represents the moment when the second order is placed. Allon and Van Mieghem (2010) discuss a firm that can use two sourcing options: a responsive nearshore source and a low-cost offshore source. The firm must determine an inventory sourcing policy to satisfy random demand over time. Their tailored, base-surge sourcing policy combines push and pull controls by replenishing at a constant rate from the offshore source and producing at the nearshore plant only when inventory is below a target. Boute and Van Mieghem (2011) analyze a global dual sourcing policy in which the company has access to two suppliers with complementary competencies: a local supplier that is responsive but more expensive and a global supplier that is cost