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An integrated vendor–buyer model with stock-dependent demand

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ABSTRACT

We develop an integrated vendor–buyer model for a two-stage supply chain. The vendor manufactures the product and delivers it in a number of equal-sized batches to the buyer. The items delivered are presented to the end customers in a display area. Demand is assumed to be positively dependent on the amount of items displayed. The objective is to maximize total supply chain profit. The numerical analysis shows that buyer–vendor coordination is more profitable in situations when demand is more stock dependent. It also shows that the effect of double marginalization provides a link between the non-coordinated and the coordinated case.

1. Introduction

In order to satisfy customer demands in today's competitive markets, critical information needs to be shared along the supply chain. A high level of coordination between vendors' and buyers' decision making is also required. The concept of joint economic lot sizing (JELS) has been introduced to refine traditional methods for independent inventory control. The purpose is to find a more profitable joint production and inventory policy, as compared to the policy resulting from independent decision making.

The idea of optimizing the joint total cost in a single-vendor, single-buyer model was considered early on by Goyal (1976). Banerjee (1986) developed the model by incorporating a finite production rate and following a lot-for-lot policy for the vendor. By relaxing Banerjee's lot-for-lot assumption, Goyal (1988) proposed a more general joint economic lot-sizing model. Lu (1995) specified the optimal production and shipment policies when the shipment sizes are equal. He relaxed the assumption of Goyal (1988) about completing a whole batch before starting shipments. Goyal (1995) then developed a model where successive shipment sizes increase by a ratio equal to the production rate divided by the demand rate. He found an expression for the optimal first shipment size as a function of the number of shipments. Later, Hill (1997) took this idea one step further by considering the geometric growth factor as a decision variable. He suggested a solution method based on an exhaustive search for both the growth factor and the number of shipments within certain ranges. Finally, Hill (1999) determined the form of the overall optimal policy. This turns out to be a combination of the policy suggested by Goyal (1995) used initially and an equal shipments policy used subsequently. However, because the policy with equal-sized shipments between the vendor and the buyer is straightforward to implement in practice, this shipment policy is usually employed in the JELS modeling literature.

The basic JELS model has been extended in several different directions. The literature on JELS may thus be divided into different categories treating issues such as quality (e.g., Affisco et al., 2002), controllable lead time (e.g., Hoque and Goyal,

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2006), stochastic lead time (e.g., Sajadieh et al., 2009), multiple buyers (e.g., Chan and Kingsman, 2007), setup and order-cost reduction (e.g., Chang et al., 2006), transportation (e.g., Ertogral et al., 2007), deteriorating items (e.g., Yang and Wee, 2000), fuzzy logic (e.g., Pan and Yang, 2008), and three-level supply chains (e.g., Khouja, 2003). Some contributions to the literature may belong to more than one of these categories. Moreover, Hill and Omar (2006) derived the optimal policy of an integrated production-inventory model where, contrary to most of the previous work, it is assumed that the unit stock-holding cost decreases as stock moves downstream in the supply chain. We refer to Ben-Daya et al. (2008) for a comprehensive review of the JELS literature. It is beyond the scope of this paper to discuss all contributions in detail.

Demand in inventory control models is most commonly assumed to be exogenous, although models with partly endogenous demand exist. In the marketing literature there is empirical evidence showing that consumer demand may indeed vary with the inventory on display or on the shelf at a retailer. For example, an investigation by Desmet and Renaudin (1998) supported the hypothesis that direct shelf-space elasticities are significantly non-zero for many product categories. In particular, they concluded that product categories typical of impulse buying have higher space elasticities. Moreover, Koschat (2008) provided empirical evidence from magazine retailing and demonstrated that the demand for a specific brand decreases as the on-shelf inventory of that brand decreases. Gupta and Vrat (1986) and Baker and Urban (1988) were among the first to introduce a class of inventory models in which the demand rate is inventory dependent. They considered a single-period model, where the demand is a polynomial function of the inventory on hand. Several other contributions extended this model to other inventory situations. Balakrishnan et al. (2004) and Urban (2005) conducted comprehensive reviews of inventory models for products exhibiting inventory-dependent demand. In particular, the latter studied two types of models in which the demand rate is either a function of the initial inventory level, or it depends on the currently available inventory level. Recently, Hariga et al. (2007) proposed an inventory model to determine the product assortment, inventory replenishment policy, display area, and shelf-space allocation decisions that maximize the retailer's profit. Abbott and Palekar (2008) studied a single-store, multi-product inventory problem in which product sales are a composite function of the shelf space. Warburton (2009) also considered the stock-dependent demand problem.

Wang and Gerchak (2001) developed models for coordinating decentralized two-stage supply chains when demand is shelf-space dependent. They characterized retailers' Nash equilibrium and explored whether the manufacturer can use incentives to coordinate such supply chains. Zhou et al. (2008) also considered the coordination issues in a decentralized two-echelon supply chain, but in cases where the manufacturer follows a lot-for-lot policy, and the demand is dependent on the inventory level on display. The Stackelberg game structure was discussed. Their model provides the manufacturer with a quantity discount scheme to entice the retailer to increase the order quantity. Also recently, Goyal and Chang (2009) proposed an inventory model with both ordering and transfer lot sizes, where the demand rate depends on the stock level displayed. However, they determined the ordering and transfer schedules based on the buyer's costs only.

In this paper, we propose a joint economic lot-sizing model for coordination in a centralized supply chain when determining the optimal vendor and buyer policies. The vendor manufactures the product in batches at a finite rate and delivers it in equal-sized transfer lots to the buyer. Some of the delivered items are displayed on the shelves in the buyer's retail store, while the rest of the items are kept in the buyer's warehouse. Final customer demand is positively dependent on the amount of items shown on the shelf/in the display area. The objective is to maximize the *total system profit when there is centralized coordination* of the supply chain members. In the sense emphasized by the italicized text, our analysis differs from and adds to the contributions referred to in the previous paragraph. The result is then compared to the total profit obtained in the corresponding non-coordinated supply chain. Finally, we also show and discuss how the so-called *double marginalization effect* (Spengler, 1950; Jeuland and Shugan, 1983; Weng, 1995) impacts the performance of the supply chain in the non-coordinated case. This provides a linkage between the coordinated and the non-coordinated supply chains.

The rest of this paper is organized as follows: In Section 2, the modeling assumptions and notation are provided. In Section 3, we develop the non-coordinated supply chain model and show how to find the independently optimal policies for the buyer and the vendor. We introduce the coordinated supply chain model in Section 4 and develop an algorithm to find the jointly optimal policy. Section 5 uses numerical examples to compare the two models. Conclusions and further research directions are presented in Section 6.

2. Assumptions and notation

The following assumptions are used throughout this paper to develop the models proposed:

1. The supply chain consists of one vendor supplying a single product to one buyer, i.e. it forms a bilateral monopoly.
2. The buyer faces a deterministic consumer demand rate $D(I)$ which is an increasing function of the stock on display I. It has the polynomial form (see e.g., Baker and Urban, 1988; Balakrishnan et al., 2004, and Zhou et al., 2008): $D(I)=\alpha I\beta$, where $\alpha > 0$ and $0 < \beta < 1$ are the scale and the shape parameters, respectively. The shape parameter, β, reflects the elasticity of the demand rate with respect to the stock level on display.
3. There is a limited capacity C_d of the display area, i.e. $I \leqslant C_d$. This limitation could be interpreted as a given shelf space allocated to the product.
4. The vendor has a finite production rate P which is greater than the maximum possible demand rate, i.e. $P > \alpha C_d^{\beta}$.