Transportation Research Part E 45 (2009) 564–571

Contents lists available at ScienceDirect

Transportation Research Part E

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

Optimizing shipment, ordering and pricing policies in a two-stage supply chain with price-sensitive demand

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ARTICLE INFO

Article history:
Received 14 June 2008
Received in revised form 11 October 2008
Accepted 2 December 2008

Keywords:
Joint economic lot sizing
Vendor–buyer coordination
Shipment policy
Pricing policy

ABSTRACT

In this paper we focus on a two-stage supply chain consisting of one vendor and one buyer. We develop an integrated production–inventory–marketing model to determine the relevant profit-maximizing decision variable values. The model proposed is based on the joint total profit of both the vendor and the buyer, and it finds out the optimal ordering, shipment and pricing policies. We are able to ascertain the optimal decision variable values employing an analytical solution procedure. The numerical evidence suggests that it is more beneficial for the buyer and the vendor to cooperate with each other when the demand is more price sensitive.

1. Introduction

In the increasingly fierce competitive environment in today's global markets, the supply chain coordination is becoming a key component. If no coordination exists, the supply chain members act independently to maximize their own profits. This independent decision behavior usually cannot ensure that the parties as a whole reach the optimal state. In traditional inventory management, the inventory and shipment policies for the vendor and the buyer in a two-echelon supply chain are managed independently. As a result, the optimal lot size for the buyer may not result in an optimal policy for the vendor, and vice versa. To overcome this difficulty, the integrated vendor–buyer model has been developed, where the joint total relevant cost for both the buyer and the vendor is minimized. Consequently, determining the ordering and shipment policies results in a reduction of the total inventory cost of the system if the determination is based on the integrated total cost function rather than the buyer's or vendor's individual cost function.

In the literature, one stream of research deals with an integrated vendor–buyer problem referred to as the joint economic lot sizing (JELS) problem. The global supply chain can be very complex, and link-by-link understanding of joint policies can be very useful (Ben-Daya et al., 2008).

Goyal (1976) first introduced the idea of a joint total cost for a single-vendor and a single-buyer scenario assuming an infinite production rate for the vendor and lot-for-lot policy for the shipments from the vendor to the buyer. Banerjee (1986) relaxed the infinite production rate assumption. Then Goyal (1988) contributed to the efforts of generalizing the problem by relaxing the assumption of lot-for-lot. He assumed that the production lot is shipped in a number of equal-size shipments. Goyal (1995) developed a model where the shipment size increases by a factor equal to the ratio of the production rate to the demand rate. He formulated the problem and developed an optimal expression for the first shipment size as a function of the number of shipments. Hill (1997) generalized Goyal's model (1995) by taking the geometric growth factor as

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doi:10.1016/j.tre.2008.12.002

a decision variable. He suggested a solution method based on an exhaustive search for both the growth factor and the number of shipments in certain ranges. Later, Hill (1999) relaxed the assumptions of the shipment policy and developed an optimal solution to the problem. He showed that the structure of the optimal policy includes shipments increasing in size according to a geometric series followed by equal-sized shipments.

The basic JELS models have been extended in many different directions. It is beyond the scope of this paper to discuss all works in detail. Broadly speaking, the existing literature on JELS may be divided into different categories such as "quality" (e.g., Affisco et al., 2002), "controllable lead time" (e.g., Hoque and Goyal, 2006), "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), "deteriorated items" (e.g., Yang and Wee, 2000), "game theory" (e.g., Bylka, 2003) and "three-level supply chains" (e.g., Khouja, 2003). Some papers in the literature may belong to more than one category. Readers are referred to Ben-Daya et al. (2008) for a comprehensive review of the JELS problems.

On the other hand, recent operations management literature has started to focus on developing integrated models that can simultaneously optimize the relevant inventory (operations) and pricing (marketing) decisions. The aim of these models is to determine the relevant operations and marketing decision variables that maximize the firm's profit. The first model of this kind was formulated by Whitin (1955) who incorporated pricing into the traditional EOQ model through a linear price-sensitive relation for the end customers. This model was later explicitly solved by Portueus (1985). Abad (1996) then addressed a similar problem for a more general demand function under the conditions of perishability and partial backordering.

Lau and Lau (2003) investigated a joint pricing–inventory model (not including setup costs). They found that the nature of the price–demand relationship may have a considerable effect on the results of multi-echelon inventory–pricing model. Viswanathan and Wang (2003) later developed a model of single-vendor, single-retailer distribution channel, where the retailer faces a price-sensitive deterministic demand. Another recent paper in this area is by Ray et al. (2005) who introduced an integrated marketing–inventory model for two pricing policies, price as a decision variable and mark-up pricing. Recently, Bakal et al. (2008) presented two inventory models with a price-sensitive demand. Two different pricing strategies were also investigated, where (i) the firm chooses to offer a single price in all markets selected, and (ii) a different price is set for each market.

Another stream of literature that deals with the pricing decision is the decentralized coordination in supply chains under a price-sensitive demand. The models introduce different types of contracts and incentive schemes to improve the performance of the supply chain and solve the "double marginalization" problem. This problem occurs when the retailer is a follower facing a price-sensitive demand and the manufacturer acts as a Stackelberg leader. However, these studies are not usable in joint economic lot sizing models. In JELS literature, the vendor and the buyer have made strategic alliances with each other. They accept to share their information, and so, despite the decentralized coordination, the decisions are made at a central point. We refer the readers to the papers by Majumder and Srinivasan (2006) and Liu et al. (2007) for this stream of literature.

The joint economic lot sizing literature and the integrated marketing–inventory literature deal with the ordering and shipment policies, and the ordering and pricing policies, respectively. In this paper, we integrate the two above-mentioned literature branches in a model where the shipment, ordering and pricing policies are optimized all together. The developed model can be considered as a JELS model in which the marketing decision is also included. On the other hand, it can be considered as an integrated operations-marketing model which is developed for a two-echelon supply chain, where production optimization is incorporated. We analyze how the coordination between two supply chain members is affected when the end customer demand is price sensitive.

The paper is organized as follows: in Section 2, the problem is defined, and notation and assumptions are introduced. Section 3 discusses the independent policies for the buyer and the vendor as well as on the integrated model. In Section 4, an algorithm is developed to find the optimal solution to the integrated model. Section 5 presents some numerical examples. Finally, the paper's findings and further research directions are summarized in Section 6.

2. Problem definition and notation

Consider a supply chain for a product which consists of a single vendor and single buyer. The final demand for this product is assumed to be deterministic but price sensitive. The lots delivered from the vendor to the buyer are equal-sized batches. As soon as the on-hand inventory at the buyer drops to the reorder point, an order of size Q is released by the buyer. The vendor manufactures the product at the production rate P and in lot sizes which are a multiple n of Q. The objective is to determine the number of shipments n, the selling price δ as well as the order size Q, so that the total profits of the vendor and the buyer are maximized. The assumptions of the model are summarized as follows:

1. The model deals with a single vendor and a single buyer for a single product.
2. The buyer faces a linear demand $D(\delta)$ as a function of selling price δ.
3. A finite production rate for the vendor is considered which is greater than the demand rate.
4. The inventory is continuously reviewed. The buyer orders a lot of size Q when the on-hand inventory reaches the reorder point.