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Integrated pricing and lot-sizing decision in a two-echelon supply chain with a finite production rate

Chuanxu Wang [a], Rongbing Huang [b,*], Qianli Wei [a]

[a] School of Economics and Management, Shanghai Maritime University, Shanghai, PR China
[b] School of Administrative Studies, York University, Toronto, ON, Canada

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ABSTRACT

In this paper, we consider a supply chain consisting of a supplier and a retailer selling the product manufactured by the supplier in a market, in which the demand for the product is decreasing in the price set by the retailer. Previous research on coordinating the supply chain with price-sensitive demand often assumes that either the supplier purchases the product or the supplier has an infinitely large production rate. We consider explicitly the supplier's finite production rate in the pricing and lot-sizing decision, which causes the problem much more challenging. We first investigate the optimization problem in the decentralized scenario to find the optimal order quantity and selling price for the retailer as well as the optimal wholesale price and lot size multiplier for the supplier. We then solve the joint optimization problem in the centralized supply chain to find the optimal order quantity, the selling price, and the optimal lot size multiplier. We provide two sequential algorithms to solve the joint optimization problem. Computational experiments show that the algorithms are effective (all 448 tested problems are solved optimally) and efficient (it only takes a few iterations to converge for each tested problem). The supply chain coordination mechanism is then designed through an all-unit quantity discount policy and a franchise fee.

1. Introduction

Integrated or coordinated pricing and lot-sizing decision has been known to be crucial in supply chain management. Effective decision can diminish conflicts among different parts of the supply chain and improve supply chain performance by reducing opportunity losses caused by separate decision.

In this paper, we focus on the joint pricing and lot-sizing problem in a two-echelon supply chain with a finite production rate, which is often neglected by previous research. We consider a supply chain consisting of a supplier and a retailer selling the product manufactured by the supplier in a market, in which the demand for the product is decreasing in the price set by the retailer. The retailer, observing the wholesale price set by the supplier, orders a certain amount of the product from the supplier regularly and sets the retail price to maximize its annual profit (annual revenue minus ordering and inventory costs). Since the manufacturing set-up costs are usually high, the supplier might be better off deviating from the policy of matching its production frequency to the retailer's order frequency. Thus, in order to maximize its profit (annual revenue minus production set-up, order processing, and inventory costs), the supplier needs to determine its production frequency and the wholesale price.

There is a considerable volume of literature that deals with various aspects of joint pricing and lot-sizing problem, which concerns simultaneous determination of a product's price and lot size to maximize a firm's profit for price-dependent demand over a planning horizon. For some of those, we refer the reader to recent papers by Chen et al. (2014), Lee (2014), Yang et al. (2014), Zhou and Chao (2014) and Chapter 10 in Simchi-Levi et al. (2014). We refer the reader to Glock (2012) for a review on the joint economic lot size problem and Chen and Simchi-Levi (2012) for a comprehensive survey of joint pricing and inventory strategies under uncertain demand. For general discussion on coordinating the supply chain, interested readers can consult with the review chapter by Arshinder et al. (2011) and its references. We coordinate the supply chain using a quantity discount scheme. Readers are referred to Chung et al. (2014) and its references for more details on quantity discount. Grubbström (2014) considers a dynamic lot-sizing problem with a finite production rate, but no pricing decision is involved. We will provide a brief review of the literature on integrated pricing and lot size decision in a supply chain under deterministic but price-sensitive demand, which is most relevant to the problem considered in this paper.

Lee (1993) examines the optimal selling price and order quantity for a retailer by applying a geometric programming (GP) approach.

* Correspondence to: Rm 282, Atkinson Building, 4700 Keele Street, Toronto, ON, Canada M3J 1P3. Tel.: +1 416 7362100x22898; fax: +1 416 7365963.
E-mail address: rhuang@yorku.ca (R. Huang).

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Demand faced by the retailer is treated as a nonlinear function of price with a constant elasticity. Weng and Wong (1993) consider a similar problem as ours under the context of the log-linear demand function. They differentiate between the supplier purchasing the product and the supplier manufacturing the product since two cases incur different average inventory for the supplier. From the supplier's perspective, they derive the optimal all-unit quantity discount policy. Parlar and Wang (1994) investigate a special case of our problem in which they assume that the retailer employs a mark-up pricing policy, which sets the price as the unit acquisition cost plus a constant percentage mark-up. Thus, the decision of the supplier influences the demand directly. Abad (1994) studies the same problem as a two-person cooperative game and identifies the Pareto frontier and the Nash bargaining solution. He assumes that the supplier's production rate is infinitely larger than the demand rate.

This research is closely related to the paper by Weng (1995), in which the author shows that supplier's quantity discount policy is not sufficient to coordinate the supply chain. Unlike our paper, Weng (1995) assumes that the supplier's lot size multiplier is given if the supplier manufactures the product by itself. Weng (1997) proposes a model of seller–buyer relationship and confirms that coordinated decisions on pricing and ordering benefit both individual chain members and the entire system. Boyaci and Gallego (2002) analyze the problem of coordinating pricing and inventory replenishment policies in a similar supply chain. Under an assumption that the supplier either order the product or produces it in an infinitely large rate, they show that an optimal policy can be implemented cooperatively by an inventory consignment agreement.

Viswanathan and Wang (2003) examine the problem of coordinating the supply chain with quantity discount and volume discount. They find that whether one discount policy is more effective than the other depends on the price sensitivity of the demand. Their limited numerical study shows that perfect coordination is achieved when volume and quantity discounts are offered simultaneously. Ray et al. (2005) study the same problem as Viswanathan and Wang (2003). However, they concentrate on the pricing problem for the retailer. More specifically, they compare the regular pricing policy with the mark-up pricing policy. They show that the mark-up pricing policy is substantially worse for the retailer only when the demand is nonlinear with high elasticity, and/or the ordering cost is high.

Abad and Aggarwal (2005) formulate a model to determine the buyer's lot-sizing and pricing policy assuming that the buyer is responsible for the freight charge and can over-declare the weight of the shipment. Khouja (2006) formulates and solves models for jointly determining the optimal price and the optimal order quantity for a price and rebate sensitive deterministic demand, which considers the impact of rebates on both pricing and inventory policies. Qin et al. (2007) consider a coordination mechanism in a supply chain consisting of a supplier and a retailer with demand that is price-sensitive. They assume that the supplier purchases the product instead of manufacture it. Using an approximation method, they convert the objective functions into quadratic functions of the retail price. They conclude that the supply chain coordination can be achieved through volume discounts and franchise fees. Yildirmaz et al. (2009) study the same single-vendor–single-buyer system. They implicitly assume that the supplier purchases the product or manufactures the product in an infinitely large rate. In addition, they include the transportation cost which is responsible by the retailer. Hua et al. (2012) investigate the retailer's optimal order lot size and the optimal retail price considering that the supplier offers free shipping. Recently, Taleizadeh et al. (in press) considered a decentralized pricing and lot-sizing problem in a VMI (vender managed inventory) system with deteriorating items, in which the production rate is also a decision variable.

Although these studies make important contributions, little has been discussed about the issue of capacitated joint pricing and lot-sizing problem. To the best of our knowledge, no research has considered the supplier's production rate explicitly in the pricing and lot-sizing decision for a supply chain under price-sensitive demand. Although Weng and Wong (1993) investigate the influence on the supplier's average inventory by the production rate, they concentrate on the supplier's all-unit discount policy instead of coordinating the supply chain. Kim and Lee (1998) examines fixed and variable capacity problems of jointly determining an item's price and lot size for a profit-maximizing firm facing price-dependent demand over a planning horizon. However, they only consider the joint optimization problem from a firm's perspective instead of a supply chain. Although Abad (2003) considers the pricing and lot-sizing problem for a perishable good under finite production, he aims at determining the optimal price and the lot size for the retailer, but not the supplier's wholesale price and production frequency.

The major contribution of this paper is to consider explicitly the supplier's finite production rate in the pricing and lot-sizing decision when demand is deterministic but price-sensitive. When the production rate of the supplier is finite, Joglekar (1988) derives the supplier's average inventory, which is incorporated in our pricing and lot-sizing decision. We provide efficient algorithms to find the optimal joint solution. As can be seen from above, most related papers assume that the production rate is infinitely large if the supplier manufactures the product, which overestimates the average inventory. We show through computational experiments that the penalty might be significant based on this assumption.

The paper is organized as follows. In Section 2, we describe the problems and the notations used throughout this study. In Section 3, we investigate individual optimization problems in a decentralized system. For the sake of completeness, we begin with a result appeared in literature, but with an easier proof. In Section 4, analysis is done for the joint problem and algorithms are provided to find the joint solution. Section 5 provides a mechanism to coordinate the supply chain through an all-unit quantity discount policy and a franchise fee. Computational experiments are presented in Section 6. We conclude the paper in Section 7.

2. Problems and notations

Consider a supplier that manufactures a product with an annual production rate R and sells it to a retailer with a unit wholesale price p. The consumer annual demand, $D(x)$, is assumed deterministic, but price sensitive to the retail price, x, set by the retailer. We focus on two commonly used demand functions: $D(x)=a-bx$ and $D(x)=ax^{-b}$. The retail price, once determined, remains constant over time.

The retailer places orders with the supplier. The order quantity, Q, once determined, also remains constant over time. Each order incurs a fixed ordering cost, S_r, to the retailer and a fixed ordering cost, S_p, to the supplier. There is no shortage or backlogging allowed. Both the supplier and the retailer incur inventory-carrying costs. The inventory-carrying cost rates for the retailer and supplier are h_r and h_s per unit per unit time, respectively. We assume that h_r is independent of the wholesale price paid and h_s is independent of the variable cost of the supplier. This assumption appears commonly in literature. Viswanathan and Wang (2003) provide two reasons of using this assumption. Joglekar (1988) shows that the supplier's manufacturing quantity should be an integer multiple, say m, of the retailer's order quantity Q. Each time when the supplier sets up its production process, it incurs a fixed manufacturing setup cost S_s to the supplier.

We will solve the following three problems sequentially. In the **decentralized problem**, the supplier and the retailer are independent firms, and each wants to maximize its own annual profit. The problem is analyzed as a Stackelberg game in which the supplier acts as the leader by deciding its lot size multiplier and