Int. J. Production Economics 145 (2013) 672–682

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Pricing, replenishment, and timing of selling in a market with heterogeneous customers

Shoshana Anily [a,*], Refael Hassin [b]

[a] Faculty of Management, Tel Aviv University, Tel Aviv 69978, Israel
[b] Department of Statistics and Operations Research, Tel Aviv University, 69978 Tel Aviv, Israel

ARTICLE INFO

Article history:
Received 10 October 2011
Accepted 10 May 2013
Available online 7 June 2013

Keywords:
Replenishment policies
Pricing
Strategic customers

ABSTRACT

We consider a deterministic pricing and replenishment model in which the retailer advertises a fixed price and the selling schedule, and customers can advance or delay their time of purchase incurring holding or shortage costs. We investigate the impact of heterogeneity in the customers' reservation prices. We show that the resulting optimal solution may be very different from that obtained when customers are homogeneous. We identify nine types of possible optimal sales strategies, and compute their profits. In particular, the solution may contain sales at several discrete points of time between consecutive replenishment epochs with no sales between them.

1. Introduction

Classic inventory models customarily assume that clients who do not find the product on the shelf upon their arrival, either quit (lost sales) or wait for the next reorder time (backlogging), see for example Section 3.3 in Zipkin (2000). Under backlogging, which holds especially for monopolists, customers, arriving when the product is not available, wait for the next replenishment. The retailer is then penalized by a shortage cost consisting of the administrative work involved in handling the shortage and the loss of good will. The shortage cost is often assumed to be proportional to the amount backlogged and possibly also to the backlogging duration.

In the more recent literature it has been recognized that customers are strategic, in particular they time their purchase to maximize their welfare, and profit maximizing sellers respond to the customers' strategy. Some of this literature is reviewed by Shen and Su (2007). In such models dynamic pricing, rationing of the amount of product on the shelves, stockpiling, and timing of sales play cardinal role. For example, short term price promotion may have several effects, like attracting customers of other brands, an increase of consumption, and stockpiling. The latter means that customers may hold inventory at a cost, in order to consume it later when the price is raised to its regular level. An explanation for the potential benefits of this behavior was given by Eppen and Libermann (1984): "Under certain conditions, price deals on nonperishable goods can benefit both retailer and customer by transferring part of the inventory holding cost from the former to the latter in return for an unusually low price."

Early papers on stockpiling are Salop and Stiglitz (1982) and Bucovetsky (1983), and more recent contributions include Hendel and Nevo (2004), Bell et al. (2002), and Lai et al. (2010). Other recent papers also consider forward-looking customers. Su (2007) considers customers who can buy at the current price or delay their purchase at a cost to purchase later. Su and Zhang (2008), Aviv and Pazgal (2008), and Mersereau and Zhang (2012) also consider forward-looking customers who can delay their purchase to enjoy future discounts, but are concerned about product availability. Liu and van Ryzin (2008), Zhang and Cooper (2009), and Cachon and Swinney (2009) consider firms that intentionally understock products to create rationing risk which induces customers to buy earlier than they would otherwise intend. Su and Zhang (2009) consider strategic sellers who use commitments to a particular quantity and compensations to customers during stock-outs. Bansal and Maglaras (2009) show how sellers can manipulate the timing of purchase of their customers by dynamic pricing. Mesak et al. (2010) discuss demand manipulation by advance selling. Papanastasiou et al. (2012) show that strategic stock-outs can be used to influence social learning, leading to higher overall product adoption and increased firm profits. A different line of strategies where consumers' demand can be manipulated by an appropriate inventory holding strategy is described by Balakrishnan et al. (2004), where consumers positively react when they observe high levels of inventory.

Our objective is to investigate the effect on the retailer's optimal strategy when customers are strategic, willing to pay for advancing or delaying their purchase due to an anticipated shortage. Examples for such behavior abound and we discuss some of

* Corresponding author. Fax: +972 3 640 9983.
E-mail addresses: anily@post.tau.ac.il (S. Anily), hassin@post.tau.ac.il (R. Hassin).

0925-5273/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpe.2013.05.021

them below. We investigate a basic deterministic problem in which the time horizon is continuous and infinite, the demand rate is constant (price dependent), and the information is assumed to be complete, i.e., the retailer knows the preferences of the customers, and the customers are aware of the price and selling periods. We assume that the price that the retailer chooses is constant over time. This assumption fits many real life situations, for example retailers that adopt the common 'everyday low price' policy (EDLP). Another case where this assumption is natural is described below, referring to the market consisting of a discount price and customers who only buy at this price.

The model that we consider here is an extension of Glazer and Hassin (1986) where customers who are willing to buy the product can buy it earlier than the time they most desire it and incur inventory holding costs, buy the product later than needed and incur shortage costs, or give-up and leave the system without buying the product. This behavior is not a result of price fluctuations, but it is rather a strategic response to the retailer's policy on when to display the product on the shelf. In other words, the retailer may avoid selling the product in certain periods if this increases its profit. By doing so, it manipulates some of the customers to advance or postpone their purchase. We follow Glazer and Hassin (1986) by assuming a stationary and deterministic model where the seller is restricted to a fixed price. Thus, instead of altering the price dynamically, the seller optimizes profits by restricting sales to certain instants, and customers respond by timing their purchase. For the case of homogeneous customers (except for the time they need the good) Glazer and Hassin (1986) found that the solution may be one of three types: Continuous sales throughout the cycle, sales only at the time of inventory replenishment, or continuous sales through an interval followed by a *no-stock interval*, i.e., an interval in which the firm does not hold stock, that ends with the next replenishment. This finding adds to classic models by explaining real cases in which sellers do not hold inventory at all. Glazer and Hassin (1990) solve the same model but with the objective of maximizing social welfare rather than seller's profits. It is shown that planned shortages may be socially desired, and indeed, a profit maximizer generates *less shortage* than is socially desirable. In particular, the policy of continuous sales throughout the cycle is never socially optimal.

The assumption of identical customers greatly limits the applicability of these results. For example, when prices can be varied, Conlisk et al. (1984) and Sobel (1984) show that with heterogeneous customers, by periodically cutting the price sharply the firm can increase its profits by selling to customers with low reservation price. Our motivating question is: *Will the qualitative results obtained by Glazer and Hassin with homogeneous customers still hold when customers differ by their reservation prices?* We identify optimal integrated pricing, replenishment, and selling schedule policy for two types of customers, each associated with its own constant arrival rate and reservation price. We show that the optimal strategy may be significantly different when having heterogeneous customers. We identify nine possible outcomes, eight of them are variations of the possible strategies with homogeneous customers, but the last one contains in between two replenishment epochs, several *no-sale intervals*, i.e., intervals in which the retailer does not sell the product, separated by sale points.

The latter type of policy may explain why in some cases firms limit their sales to discrete points of time and by doing so they manipulate their customers. We next describe a few examples where the product is sold at a pre-specified set of time epochs: (i) The Tuesday Morning chain of stores is known for its unique philosophy: "sell first-quality, famous designer and name-brand merchandise at extraordinarily discounted prices on an event basis... usually on the first Tuesday of the month". (ii) All over the world it is common to have market days, so that goods are not continuously available. Of course there might be various reasons for regular market days, like resource availability, low demand, and seasonal demand; our model provides another interesting view. (iii) Many firms offer periodical discounts which can be interpreted as discrete sales as mostly in between two discount periods, the sales are low (as the price is high). Such periodic discounting also has been discussed in the bullwhip effect literature. In between periods, the consumers typically forward buying their needs for the whole period. Our model could describe such price discount events. The product is sold continuously, but at certain times the price is vastly reduced. Many customers will try to wait for those discounts. Our model focuses on those customers who always wait for discounts. The other customers are outside the model. The special sales may then be repeated for a very short period (say, a day or a weekend). Since customers are aware of the special sales they will only buy on sales periods and will carry the inventory for future days when the price is high. (iv) The situation we are analyzing might occur in some of the home appliances and office equipment retail chains (e.g., Ace, Home Depot, Office Depot). It is quite common to find in these chains that they sell an item over a certain period, then it is taken off the shelf only to be returned a few weeks later. Sometimes this happens because they get bulk shipments in containers (typically from China) and sometimes there is discontinuity in the shipments of this product. Another explanation for these planned shortages is given by our results. (v) Many computer games (such as the popular Call of Duty series) have a new edition released once or twice a year, causing a period of sales of the original game followed by long no sales intervals. (vi) As our results show it is possible to have an optimal policy where the product is first sold continuously and then it is sold at a number discrete points until the next continuous sales interval. An example for such a mixed behavior is the real-estate industry, and in particular in Hong Kong. The replenishment is the time completion of a project, and the developers adopt various strategies to sell the apartments (see, Lai et al., 2004 for more examples and discussion): One-time clear strategy, is when a big real-estate project is finished, the developer offers a reasonable price and consumers buy all apartments at the selling date. Usually it just takes one or several days to sell thousands of apartments. Alternatively, in a continuously selling strategy the developer offers a pretty high price and consumers come continuously and it may take one year to sell one thousand apartments. In yet another strategy that is employed, apartments are sold one year before they are used, resulting in consumers who need wait before moving in bearing a very high holding cost. (See the new regulation on selling price and quantity in the Hong Kong real estate market athttp://www.info.gov.hk/gia/general/201005/26/P201005260094.htm and in particular Part (c).)

We note however, that the solution type where there are a number of discrete sales epochs in between two consecutive replenishments, is less frequently observed relative to the other eight cases, and one of our goals is to characterize the conditions under which this solution is obtained. In particular, we show that this solution requires that the consumers shortage costs be higher than their inventory holding cost, and that the firm's fixed replenishment cost is high.

The assumption that customers are charged for shortages and for holding inventory, endogenously and indirectly induces a shortage cost for the retailer without necessitating an assessment of unit shortage/backlogging cost by the firm. The strategic use of no-sale intervals may cause some of the customers to quit without buying. Indeed, the higher are the holding/shortage costs faced by the customers, more customers will quit in a no-sales interval, inducing a higher shortage penalty cost on the retailer. The