A note on limited clearance sale inventory model

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The increasing trend in markdowns over the past few decades indicates that over orders and high clearance inventory are becoming a common phenomenon in retailing. When the clearance inventory is high there are many situations wherein the marginal revenue as a result of reducing the clearance price below a particular level is negative. In such situations, the retailer is better off clearing only part of the leftover inventory and disposing the remaining for free. We model the limited clearance sale inventory problem for determining the optimal order quantity, and establish the coordination mechanism for wholesale price, buy-back, revenue sharing and sales rebate contracts.

1. Introduction

Managing uncertainty is a critical challenge faced by retailers of short product life cycle or single season products like apparel, consumer electronics, mobile phones, personal computers and event merchandise. Under ordering results in stock outs while over ordering results in leftover inventory that would have to be exhausted through a clearance sale. Fisher and Raman (2010) report that US retailers accumulate so much excess inventory that markdowns have increased from 8% in 1970 to nearly 30% at the turn of the century. Apart from this statistic, there is strong evidence to point that over ordering is today a common phenomenon in retailing. John Lewis posted record sale on the first clearance day after Christmas even during the economic downturn of 2008 (Potter, 2008). In 2012, Boxing Day posted record clearance sale across UK retail websites (Peachey, 2012). The complexities of global supply chains force retailers to stock up products at the beginning of the season itself, with little information about what the demand would be, in spite of past ordeals with clearance sales. Post-season discounted-sale or clearance sale is the most prevalent form of clearing leftover inventory (Forest et al., 2003; Cachon and Küç, 2007; Wang and Webster, 2009). Retailers are also careful about providing discount, as excessive discounting to clear inventory may lead to revenue reduction and brand dilution. Innoveventure, a Japanese company, helps manufacturers to dispose of their excessive inventories as gifts or premiums. To protect against brand dilution, Adries Dolls, a premium baby clothing company, provides a limited discount sale at the end of selling season. Thus, there are many retail situations where apart from deciding the order quantity before the start of the period, the retailer has to decide at the end of the period the amount of left over inventory that would be subjected to clearance sales and the price at which they would be cleared. The latter, which depends on the inventory at the end of the period, is a function of the initial order quantity decision as well as the actual demand that was observed in the period.

This note models the limited clearance sale inventory problem for determining the optimal order quantity and establishes the coordination mechanism for wholesale price, buy-back, revenue sharing and sales rebate contracts. Section 2 reviews the literature relevant to this research, §3 models the limited clearance sale inventory problem, §4 describes the modelling of supply contracts for limited clearance sale inventory problem and the conditions under which they coordinate the supply chain, and the discussion of the results and conclusion are described in §5.

2. Literature review

Retail sales and clearance pricing has received sufficient attention in the field of economics (Nocke and Peitz, 2007). While Lazear (1986) proposes the theory of clearance sales, Pashigian (1988) extends it to allow for industry equilibrium. In both the papers uncertainty in demand is owing to the retailer not knowing the customer reservation price while setting the initial price and the models determine the optimal initial and markdown price to be set by the retailer to maximise expected revenue. These optimal prices do not rule out the probability of sales not happening at either the initial or markdown price. Such a left-over is assumed by Pashigian (1988) to be cleared at zero value.

The operations management inventory literature views clearance
sales problem differently. It assumes an initial retail price that is set exogenously and a demand uncertainty during the season that follows a probability distribution. The vast majority of operations management literature also assumes an exogenously set clearance price (described as salvage value) and uses the famous single period newsvendor model to determine the optimal order quantity. The newsvendor model is a well-studied problem. Khoury (1999) builds taxonomy of the newsvendor model literature and delineates the contribution of the different extensions. A few extensions of newsvendor model focus on simultaneous choice of stock quantity and initial pricing decision (Petruzzi and Dada, 1999; Agrawal and Seshadri, 2000; Murray et al., 2012; Serel, 2008). Most of these models assume clearance prices to be exogenous and the decision maker chooses the regular selling price only. Recent works on multi-period newsvendor model have often taken similar assumption of fixed salvage value (Alfares and Elmorra, 2005; Donohue, 2000; Fisher et al., 2001; Petruzzi and Dada, 2001; Xu et al., 2011). There are numerous articles that study markdown pricing under the assumption that the demand is independent across the time and do not allow for correlation in demand (Bitran and Mondshein, 1997; Kevin Weng, 1999; Smith and Achabal, 1998). Dana and Petruzzi (2001) extend the newsvendor problem for endogenous demand where the uncertain demand is dependent on both the price and the inventory level of a firm.

Scholars and empirical evidence (Hertz and Schaffir, 1960; Rozhon, 2005; Kratz, 2005) indicate that the salvage price is variable and is dependent on the leftover inventory. For the purpose of modelling simplicity, literature has assumed a fixed unit salvage value. Hertz and Schaffir (1960) do not estimate the salvage value and argue that constant salvage value is an adequate approximation. Porteus (1990), in his extension of newsvendor model, shows that the objective function behaves well for a loss function that has convex holding and shortage costs, and derives the optimality condition. Cachon and Kök (2007) question the fixed salvage value assumption and describe the errors in decision making that are associated with this assumption. Instead of a constant salvage value, they propose a general clearance-pricing model that assumes iso-elastic clearance period demand functions. The clearance pricing model is somewhat similar to the newsvendor model except that a clearance price is chosen at the start of the clearance period such that revenue is maximised based on the inventory available at the beginning of the clearance period. They also propose four heuristic approaches to estimate a fixed salvage value that would result in better decision-making when using the newsvendor model. Among the heuristics proposed the weighted average salvage value heuristic results in newsvendor decisions that are closest to the optimal solution. Another heuristic, the marginal heuristic, is optimal in linear order quantity but is difficult to estimate and is specific to the clearance pricing model proposed by the authors.

There are innumerable examples, ranging from clearance sales of perishable goods to end of season sales of fashion goods, where the price at which the inventory is cleared at the end of a period (season) is a decreasing function of the inventory leftover and the price elasticity of demand is not constant (Sen and Zhang, 2009; Caro and Gallien, 2012). Behavioural research and industry experts suggest that price elasticity changes with change in price level and also according to stages of product life cycle (Lilien et al., 1992). As clearance sale advances, consumers become less sensitive to price (Caro and Gallien, 2012). Such behaviour cannot be modelled by iso-elastic or exponential demand functions; exponential demand function exhibit constant price elasticity of demand with price approaching infinity when the price approaches zero. Variability in price elasticity can be simply captured by linear demand function. Linear form of demand function often faces the criticism of being restrictive in terms of maximum permissible price (Varian, 1992; Huang et al., 2013). However, the same is not the case with modelling of clearance-sale demand. The clearance price or salvage value will always have an upper limit given by the normal period price (Cachon and Kök, 2007; Wang and Webster, 2009).

We briefly review the related supply contract literature here. A large number of research papers address the issue of supply chain coordination through contracts in the presence of stochastic demand using newsvendor model. Employing newsvendor framework, Pasternack (1985) shows that in a dyadic relationship an optimal return policy can achieve supply chain coordination where the supplier offers the retailer full credit for a partial return of goods. Lariviere and Porteus (2001) provide a detailed analysis of wholesale contract in the context of newsvendor problem. This contract though fails to coordinate a supply chain, generally serves as a benchmark case. In the similar context, Pasternack (1985) gives a complete analysis of buy-back contract and demonstrates how this contract helps in coordinating a supply chain. Cachon and Lariviere (2005) analyse revenue sharing contract in a generalized newsvendor setting and show how coordination is possible employing such a contract. Taylor (2002) and Krishnan et al. (2004) discuss the sales-rebate contract in the context of random retailer demand and prove the existence of coordinating contract mechanism. In the context of newsvendor framework, Cachon (2003) provides a comprehensive review of these types of contracts. All these contract analyses assume an exogenously decided constant salvage value. Wang and Webster (2009) assume the clearance pricing to be endogenous to the model and then compares between two different types of the contracts based on quantity and price markdown.

Literature review indicates that a clearance pricing model is superior to the newsvendor model while determining the optimal order quantity when salvage value is dependent on the leftover inventory. However, a clearance pricing model designed for iso-elastic demand is not valid for all retail situations. Based on Lazear (1986), Pashgian (1988), Şen and Zhang (2009), and Caro and Gallien (2012) we argue that there are many retail situations that warrant only a limited clearance of leftover inventory in order to maximise the retailer revenue. A linear demand function is more appropriate in such a situation. We extend the Cachon and Kök (2007) clearance pricing model for a linear clearance demand function, which we designate as the limited clearance sale inventory model. A separate section deals with the modelling of supply contracts and determination of their coordination mechanism for the limited clearance sale inventory problem, which has again not been studied.

3. The limited clearance sale inventory (LCSI) model

We model the problem as one with two periods: a normal period ($P_1$) where the good is sold at a pre-determined price $p$ and a clearance-sale period ($P_2$) where the good is cleared at a price $v$. As in the newsvendor model, the order quantity $q$ that was procured at a marginal cost $c$ is available for sale at the beginning of $P_1$. The unit selling price $p$ during the normal season is assumed to be fixed (Pasternack, 1985; Cachon and Kök, 2007; Wang and Webster, 2009) such that $p > c$. However, unlike in the newsvendor model, the clearance price $v$ is decided only at the end of $P_1$ after observing the leftover inventory. Table 1 below captures the distinctiveness of the Limited Clearance Sale Inventory (LCSI) model from Newsvendor model. The objective of the LCSI model is to maximize the expected profit $\pi(q) = R_1 + R_2 - c q$, where $R_1$ and $R_2$ are the expected revenues in periods $P_1$ and $P_2$, respectively.

The demand during $P_1$ is given by $x$, and is distributed over $[0, q_{max}]$. The demand is assumed to follow an increasing generalized failure rate (IGFR) distribution; the corresponding probability distribution and cumulative distribution are represented by $f(x)$ and $F(x)$, respectively. We further assume that $f(x)$ and $F(x)$ are differentiable over the entire range $[0, q_{max}]$. $F(x)$ is strictly increasing; the boundary conditions of the distribution are: $F(0) = 0$ and $F(q_{max}) = 1$.

Like Cachon and Kök (2007), we assume that the demand in $P_2$, denoted by $d$, is a function of the clearance price $v$. However, we focus on real life situations where companies fail to clear large leftovers. In such situations, rather than aiming to clear the entire inventory at a clearance price much lower than the marginal cost $c$, the firm would be revenue-wise better off clearing a portion of the inventory at a higher clearance price and the remaining inventory at zero salvage value. The
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