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The influence of sale announcement on the optimal policy of an inventory system with perishable items

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ABSTRACT

In this paper a single-period inventory system with a sale announcement for perishable items is investigated. In this problem setting, the perishable product has a deterministic expiry date and a demand with a probabilistic behavior during the period. When the expiry date of the product is approaching, a special sale announcement may alter the customers' behavior and escalate the demand rate preventing huge loss of the expired products. Two model is developed to obtain the optimal order quantity of the product and the optimal time for sale announcement. The first model considers a static price dependent behavior of customers independent from the product's expiry date, while in the second one the product's demand rate after sale announcement is assumed as an increasing function of its remaining lifetime. Usefulness of the proposed models and the influence of sale announcement on total revenue is demonstrated using numerical examples. Finally, a comprehensive sensitivity analysis is conducted revealing the effect of different parameters of the models on the optimal policy.

1. Introduction

Perishable items are often modeled as a single-period problem known as newsvendor problem which the product should be ordered at outset and be sold during the period (Krider and Weinberg, 2000). In the basic form of a single-period inventory model, the buyer decides about the optimal quantity of purchased product at outset of the period with a probabilistic demand. There are different versions of the single-period inventory problem in the literature. Moon and Silver (2000) and Abdel-Malek et al. (2004) studied the problem for the budget constrained multi-item case. Serel (2008) integrated inventory and pricing decision in the newsvendor problem. Ölzer et al. (2009) investigated value-at-risk constraint in the single-period problem. Chen and Chen (2010) proposed a multiple-item newsboy problem with constrained budget and a reservation policy. Qin and Kar (2013) developed a single-period inventory model considering uncertain environment. Kamburowski (2014) considered the distribution free version of the problem under the worst-case and best-case scenarios. Rossi et al. (2014) modeled a new method to estimate demand by combining inventory optimization and statistics. A price-setting newsvendor is investigated by Ye and Sun (In press) with strategic consumers to determine optimal selling price and stock quantity while this problem is studied by Rubio-Herrero et al. (2015) under mean-variance criteria. A single-period problem considering late season low inventory assortment effects is investigated by Khouja (In press). Recently, Carrizosa et al. (2016) developed a robust approach to maximize the revenue in worst-case with autoregressive demand for the newsvendor problem.

Sale announcement has been one of the most effective tools to motivate consumers. Also, this strategy is an accepted way for retailers when expiration date of their perishable goods is approaching (Donselaar et al., 2006). Nowadays, advancements in intelligent identification and information systems has made waste reduction easier than past (Pramatari and Theotokis, 2009). On the other hand, recent researches show that sale announcement may have an impact on customer trust in a negative way reducing goodwill of the brand (Xia et al., 2010). Especially for food products, the sale announcement may be interpreted as a sign of decreasing quality or a very close expiration date. From the consumers' viewpoint, newly produced high quality products with a reasonable price are preferred. However, any price-cut will result to a trade-off problem between cost and quality of the product. From the retailer's point of view, quality of the product is expressed by the precisely calculated expiration date and quality of the product before its expiry date is assumed perfect. These conflicting perspectives have made the timing a discount as a crucial problem where a too soon or too late price-cut leads to a sub-optimal policy (Johnson et al., 2013).

There are several works considering a variety of predefined sales and discount policies in the literature of the inventory planning systems (Zhang, 2010; Chen and Ho, 2011; Theotokis

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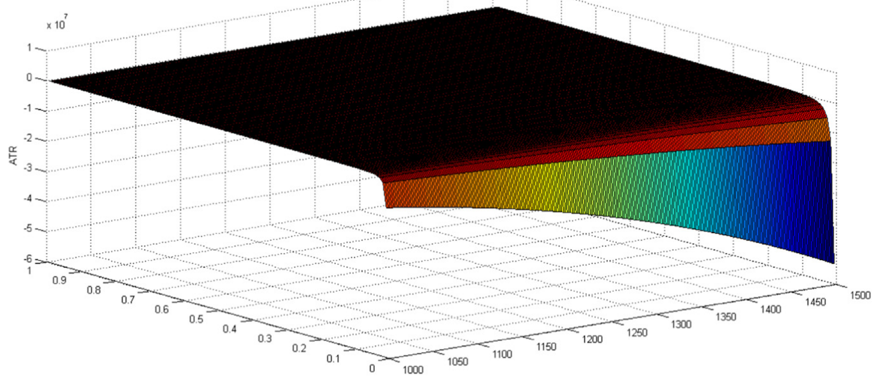

Fig. 1. Average total revenue for a uniformly distributed expiry-date-independent demand.

et al., 2012; Tromp et al., 2012; Chen and Ho, 2013). Based on the author's knowledge, despite the importance of the timing of sale announcement in a single-period problem, there is no previous research in the literature addressing this issue. The key contributions of this paper are: (1) Extension of a single-period inventory system to obtain the optimal time of sale announcement and optimal order quantity at outset of the period. (2) Extension of the proposed model considering that consumers demand behavior after announcement of sale is a function of remaining time to expiration date. (3) Sensitivity analysis and comparison of the proposed models with the basic single-period model using several numerical examples.

2. Proposed models

In this section two novel version of the single-period inventory model is extended with a distribution-free structure for demand rate. Then the solution approach is presented for two special cases, i.e, uniform and exponential distributions.

2.1. First model: expiry-date-independent demand

In this subsection, the newsboy model is extended supposing that the retailer will announce a special sale to motivate consumers to buy more. It is assumed that sale price is predefined and the average demand after the sale announcement is given independent from remaining time to expiry date. Let x_1 and x_2 denote the random variables of demand per time unit before and after sale announcement with expected values of $E(x_1)$ and $\mathrm{E}(x_2)$, and probability distribution functions of $f_{X1}(x_1)$ and $f_{X2}(x_2)$, respectively. Let v_1 and v_2 denote the known unit selling price before and after sale announcement, respectively. Also let c, π and h denote unit purchasing price at outset of the period, unit shortage cost during the period and unit waste cost of redundant product at end of the period, respectively. The average total revenue of the basic newsvendor problem is as follows Abdel-Malek et al. (2004):

$$E(Z)=(v_1+h)E(x_1)-\left[(c+h)R+(\pi+v_1+h)\bar{b}_1(R)\right] \quad (1)$$

where the decision variable, R, is the quantity of purchased product at outset of the period and $\bar{b}_1(R)$ is the average shortage during the period. The cumulative probability in the optimal value of R to maximize $E(Z)$ can be expressed as follows:

$$F_{X1}(R^*)=\frac{(\pi+v_1-c)}{(\pi+v_1+h)} \quad (2)$$

At the moment which retailer announces a special sale after a fraction τ of the period's outset, the average remaining inventory is as follows:

$$R'=R-\tau E(x_1)+\overline{b_1}(R) \quad (3)$$

Considering R'as the initial quantity of the product after sale announcement the average total revenue of the proposed newsvendor problem can be obtained as follows:

$$ATR(\tau,R)=\tau(v_1+h)E(x_1)+(1-\tau)(v_2+h)E(x_2)-\Big[(c+h)R+(\pi+v_1+h)\overline{b_1}(R)+(\pi+v_2+h)\overline{b_2}\big(R-\tau E(x_1)+\overline{b_1}(R)\big)\Big] \quad (4)$$

2.2. Second model: expiry-date-dependent demand

When retailer announces a special sale, consumers' behavior depends on the remaining time of the products lifetime. In this subsection, it is supposed that the average demand per time unit is an increasing function of $(1-\tau)$ as follows:

$$\mathrm{E}(x_2)=\mathrm{E}(x_1)+A(1-\tau)^B \quad (5)$$

where A and B are control parameters of the function. By replacing $\mathrm{E}(x_2)$ in Eq. (4) with Eq. (5), the average total revenue function can be stated as follows:

$$ATR(\tau,R)=\tau(v_1+h)E(x_1)+(1-\tau)(v_2+h)\big(\mathrm{E}(x_1)+A(1-\tau)^B\big)-\Big[(c+h)R+(\pi+v_1+h)\overline{b_1}(R)+(\pi+v_2+h)\overline{b_2}\big(R-\tau E(x_1)+\overline{b_1}(R)\big)\Big] \quad (6)$$

The optimal policy for the proposed models are the values of τ and R maximizing $ATR(\tau,R)$ functions described in Eqs. (4) and (6), respectively. Behavior of the $ATR(\tau,R)$ functions depends on the probability distribution of demand while their convexity is not guaranteed, so extracting a closed form optimal solution for a distribution-free structure is impossible.

2.3. Special case 1: uniform distribution

Suppose that product's demand per time unit before and after sale announcement, x_1 and x_2, are uniformly distributed between (a,b) and (a',b'), respectively. For the first proposed model, $a'\geq a$ and $b'\geq b$ are assumed independent from $(1-\tau)$. In this case we have:

$$ATR(\tau,R)=\tau(v_1+h)\frac{(a+b)}{2}+(1-\tau)(v_2+h)\frac{(a'+b')}{2}-\left[(c+h)R+(\pi+v_1+h)\frac{(\tau b-R)^2}{2\tau(b-a)}+(\pi+v_2+h)\frac{((1-\tau)b'-R+\tau\frac{(a+b)}{2}-\frac{(\tau b-R)^2}{2\tau(b-a)})^2}{2(1-\tau)(b'-a')}\right] \quad (7)$$

For the second proposed model, $a'\geq a$ and $b'\geq b$ are assumed