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Optimal ordering and pricing decisions for a target oriented newsvendor

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ABSTRACT

This paper is the first to study pricing and target oriented decision making together in the newsvendor model. Specifically, this paper studies a newsvendor who decides on order quantity and selling price to maximize the probability of achieving both profit and revenue targets simultaneously. First, it is shown that the probability of a newsvendor achieving both targets depends critically on the relative magnitudes of the profit margin and the ratio between the profit target and the revenue target. Second, the closed-form expressions of the optimal order quantity, the optimal selling price, and the maximal profit and revenue probability are obtained. It is shown that if the product has greater price elasticity, the best strategy is always to price lower and order more.

1. Introduction

The classical newsvendor (NV) or the single-period model has been a simple yet powerful building block to study various business scenarios, including inventory management, supply chain management, yield management, scheduling, and option pricing [1]. As a result, a great amount of research has been done on the model and its various extensions. See Khouja [2] for an excellent review of the literature before 1999. More recently, Wu et al. [3] studied the NV model with the mean-variance objective function, where stockout cost is incorporated explicitly. Chen et al. [4] studied a price-setting NV adopting the criterion of Conditional-Value-at-Risk, a risk measure commonly used in finance. Keren [5] studied a special NV with deterministic demand but random supply. He considers both the additive and multiplicative forms of supply randomness. Feng et al. [6] conducted a laboratory experiment to examine the difference in ordering behaviors between Chinese and American decision makers. They find that Chinese subjects have a higher tendency to order according to the mean demand.

Two particular extensions of the NV model are of the interest of this paper. The first extension is the price-setting NV, an excellent review of which is given in [7]. The second extension is the target oriented NV, namely, an NV maximizing the probability of achieving targets on various performance measures. For a review of earlier work on this extension, readers are referred to [2]. Lau and Lau [8] studied a profit-target oriented newsvendor selling two products. The problem is shown to be surprisingly challenging with important managerial insights. More recently, Parlar and Weng [9] studied an NV maximizing the probability of achieving the expected profit, which itself depends on the order quantity. Brown and Tang [10] explored the optimal ordering behavior for an NV under alternative performance measures including meeting target on profit or sales. Shi and Chen [11] studied a supply chain where a supplier sells to a retailer (an NV) and both are profit-target oriented. Finally, Wang and Webster [12] studied a loss-averse NV, which is equivalent to a profit-target oriented NV when the loss-aversion coefficient is sufficiently large.

In this paper, we make a main contribution by combining the price-setting NV and the target oriented NV. To be more specific, we study an NV who decides on order quantity and selling price to maximize the probability of achieving both profit and revenue targets simultaneously. Furthermore, we make a secondary contribution by incorporating both profit and revenue as performance measures. A closely related paper is [10], where meeting targets on profit or sales (total revenue minus the revenue due to salvage) are considered separately. Furthermore, pricing is not considered in [10].

In business practice, it is of great importance for firms to meet targets on both profit and revenue at the same time; missing *either* may lead to serious consequences. Two recent examples are listed here. In the 3rd quarter of 2002, Intel, the largest microchip manufacturer in the world, hit its revenue target but missed its profit target by a small margin. Consequently, its stock price dropped by 15% and the Nasdaq was down by nearly 3%. In the 3rd quarter of 2005, Yahoo! reported $875 million in revenue, a 44% gain over the same period the year before. However, the consensus revenue estimate was for $881 million. As a result, the stock was down 10% in after-hours trading.

The importance of achieving both profit and revenue targets has also been documented in the literature. Simon [13] states that most firms' goals are to attain targets on performance measures including profit and revenue. In a classical economics book,

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Baumol [14] advocates that the objective of firms is revenue maximization subject to profit-target constraint. Shipley [15] studied the pricing objectives of 728 British manufacturing firms. It is found out that 87.8% of the firms specify a profit target or a target rate of return on capital and 47.0% of the firms specify a revenue target. More recently, Brown and Tang [10] surveyed professional buyers (NVs) whose jobs are to order fashion items for companies such as Sears and J.C. Penny. They find that the buyers' important performance metrics include meeting targets on profit or sales.

The remainder of this paper is organized as follows: in Section 2, we first present the results on a profit-target oriented NV and then study a revenue-target oriented NV. Then in Section 3, we study an NV with both profit and revenue targets to achieve. In Section 4, we study a price-setting NV with both profit and revenue targets. We summarize our results and suggest future research in Section 5.

2. Newsvendor with a profit or revenue target

In this section, we first present the results on a profit-target oriented NV. We then study an NV whose objective is to achieve a pre-determined revenue target. Our purpose in this section is to provide a basis for later analyses.

Consider an NV with a unit ordering or procurement cost c and a unit selling price r. The customer demand D, a non-negative random variable, has a cumulative distribution function $F(\cdot)$. The NV has only one order opportunity and has to determine her order quantity before the actual demand is realized. If the NV under-orders, she will suffer lost sales. For simplicity, zero good-will cost is assumed and the underage cost is just the loss of revenue. If she over-orders, she will dispose the unsold inventory at salvage price $v<c$, which leads to a loss as well. To avoid distractions, v is assumed to be positive and $F(\cdot)$ is assumed to be strictly increasing and differentiable.

If an NV has only a profit target t^p to achieve, her objective is to maximize the profit probability (denoted by P^p), namely, the probability that her profit meets or exceeds t^p. The profit probability as a function of the order quantity is given as [2]

$$P^p(q)=\begin{cases}0 & \text{if } q<t^p/(r-c)\\ 1-F\left(\dfrac{(c-v)q+t^p}{r-v}\right) & \text{if } q\geq t^p/(r-c)\end{cases} \tag{1}$$

Therefore, the profit probability decreases with order quantity when $q\geq t^p/(r-c)$.

If an NV is revenue-target oriented, her objective is to maximize the revenue probability (denoted by P^e), namely, the probability of achieving a pre-determined revenue target t^e. We have the following proposition.

Proposition 1. *The revenue probability of a revenue-target oriented NV is given by*

$$P^e(q)=\begin{cases}0 & \text{if } q<t^e/r\\ 1-F\left(\dfrac{-vq+t^e}{r-v}\right) & \text{if } t^e/r\leq q<t^e/v\\ 1 & \text{if } q\geq t^e/v\end{cases} \tag{2}$$

All the proofs are given in the Appendix. It can be seen from (2) that overall, the revenue probability (weakly) increases with regard to order quantity. The NV has to order at least t^e/r to make the revenue target achievable at all. The revenue probability keeps increasing until the order quantity becomes t^e/v, after which point the revenue target will definitely be achieved. This is because even under the worst demand scenario, i.e., $D=0$, the NV can still achieve the revenue target by simply salvaging all the stock. However, the order quantity t^e/v may be unrealistically large for short life-cycle items with low salvage value. In terms of managerial insights, (2) implies that the NV always has the incentive to order up to t^e/v when revenue is the only concern.

Table 1
The optimum of an NV with a profit target t^p or a revenue target t^e.

	Optimal order quantity	Maximal profit or revenue probability
With a profit target	$\frac{t^p}{r-c}$	$1-F\left(\frac{t^p}{r-c}\right)$
With a revenue target	$\frac{t^e}{v}$	1

Based on the profit probability as in (1) and the revenue probability as in (2), we can obtain the optimal order quantity and the maximal profit or revenue probability, which are summarized in Table 1.

It would be useful to compare a profit-target oriented NV with a classical NV who maximizes the expected profit. As an illustration, we have the following numerical example.

Example 1. Consider the following scenario: $r=12$, $c=5$, $v=3$ and customer demand D follows a normal distribution with a mean of 150 and a standard deviation of 30. In Fig. 1, the dashed lines correspond to a classical NV: the maximal expected profit is 969.6 and the probability of achieving it is 64.9%. Hence, although the *expected* profit is maximized, there is a probability of 35.1% that the *actual* profit will be less than 969.6. As a comparison, the solid lines in Fig. 1 represent a profit-target oriented NV. As the pre-determined profit target increases from 600.0 to 1600.0, the expected profit associated with the optimal order quantity first increases from 598.4 to the maximal expected profit (969.6), then decreases to 892.5. Moreover, the profit probability decreases from 98.4% to 0.4%. Therefore, comparing with a classical NV, a profit-target oriented NV may have a lower expected profit, which, however, is offset by a larger profit probability.

3. Newsvendor with both profit and revenue targets

Now suppose that an NV has both a profit target t^p and a revenue target t^e to achieve at the same time. To avoid trivial scenarios, it is assumed that $t^e>t^p>0$. The objective of the NV is then to maximize the probability of achieving both targets simultaneously, i.e., $P=\Pr\{\Pi^p\geq t^p \ \& \ \Pi^e\geq t^e\}$. Similarly, we call P the profit and revenue probability.

Before we proceed, for notational simplicity, we define the profit margin of the product as $\alpha=(r-c)/r$, and the target ratio as $\beta=t^p/t^e$. Obviously we have that $0<\alpha<1$ and $0<\beta<1$. Note that the target ratio β is an indicator of the importance of growth and revenue for a firm; a lower β corresponds to a larger revenue target and a higher priority on growth and revenue.

Theorem 1. *Suppose that an NV has both a profit target t^p and a revenue target t^e to achieve. If the profit margin is not greater than the target ratio, i.e., $\alpha\leq\beta$, her profit and revenue probability $P(q)$ is equal to the profit probability given by (1). If $\alpha\geq\beta$, her profit and revenue probability is given by*

$$P(q)=\begin{cases}0 & \text{if } q<t^e/r\\ 1-F\left(\dfrac{-vq+t^e}{r-v}\right) & \text{if } t^e/r\leq q\leq (t^e-t^p)/c\\ 1-F\left(\dfrac{(c-v)q+t^p}{r-v}\right) & \text{if } q\geq (t^e-t^p)/c\end{cases} \tag{3}$$