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Risk tolerance and a retailer's pricing and ordering policies within a newsvendor framework

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ABSTRACT

This paper evaluates the pricing and ordering policies of a retailer, facing a price-dependent stochastic demand, within a newsvendor framework, under different degrees of risk tolerance and under a variety of optimizing objectives. These are (i) maximizing expected profit, for a retailer who may be risk-seeker, risk-averse or risk neutral; (ii) deriving a maximin strategy of maximizing a minimum guaranteed profit and (iii) modeling the probability of exceeding a target profit, as a constraint or as an objective. Some analytical properties and numerical examples illustrate the main features of the models and provide some comparative policy analysis across the model.

1. Introduction

In the classical newsvendor problem (NVP), a risk-neutral firm facing a random demand decides the order quantity that maximizes its expected profit. The earlier NVP methodology assumes demand to be independent of price. Thus, the standard order-quantity results from the trade-off between the costs of under and over-stocking of units initially intended to meet the forecasted demand. The increasing importance of the tertiary over the secondary sectors of the economy worldwide and the lowering of product life cycles, as a result of the increasing importance of time-based competition, has substantially enhanced the incidence of single-period problems where the decision maker has to order ahead to satisfy an uncertain demand for an item/service that cannot be inventoried. Khouja [22] describes over 11 areas, ranging from multi-location problems to random yields, to different supplier pricing policies, where NVP formulations are of use. This depth and breadth of applications clearly attest to the saliency of the NVP in solving many strategic and tactical problems and to its flexibility to model cross-functional integration. Recent reviews of this topic appear in [8,9,22,31].

It should be pointed out from the outset that the term risk used in the current paper refers to the firm-specific or unique risk, as against the systematic risk, typically considered relevant in the finance literature. The underlying argument is that some of the risk may be eliminated if the returns from inventory investment are correlated with other investment returns. Hence, only the systematic or non-diversifiable risk needs to be considered for decision making. There are a few papers that have used the capital-asset-pricing model to characterize risk in a NVP (e.g. [4]). On the other hand, even if the systematic risk may be relevant for investors, because they have opportunity to diversify, a financial manager is rewarded by his/her own performance and, therefore, may not have the same opportunity to diversify. This explains, for example, the preference of unique risk reduction, as a motive for conglomerate mergers (e.g. [3]). Furthermore, managers who have to keep the interest of other stakeholders, like employees, have an ethical obligation to protect them against bankruptcy risk, a risk easily diversifiable for an investor [18]. In any event, for our paper, we focus on the unique risk, following the vast majority of the *NVP* literature.

The purpose of this paper is to evaluate the pricing and ordering policies of a retailer who is facing a price-dependent stochastic demand, within a newsvendor framework, under different degrees of unique-risk tolerance and under a variety of optimizing objectives. Observe in the stated purpose the attempt to integrate three important streams of thought, being used, albeit separately, to adapt the NVP formulation to modern concerns. A brief explanation of these three topics follows.

Early works on the subject (e.g. [23,24,30]), considered cases, where the newsvendor is risk neutral and the selling price is

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constant and hence independent of demand and the objective to be optimized is the maximization of expected profit. Undoubtedly, a major shift in NVP modeling occurred upon recognition of the micro-economic principle of price-induced demand. Using the selling price as a decision variable provides the decision maker with an additional tool, with which to counteract the vagaries of demand uncertainty, in accordance to the standard tenets of micro-economic theory (e.g. [5]). This NVP does not restrict the retailer's decision process to simply placing an order at a fixed retail price. Instead, the retailer decides the price and order quantity that optimizes the expected profit. Recent reviews from this perspective appear in [9,31]. The other two underlying assumptions in most of the models in the literature are that the retailer is risk-neutral and that the desired objective is to maximize the expected profit. Schweitzer and Cachon [32], in their experimental study, where the buyers were deciding over quantity for a given price and demand distribution, observe that the retailer's behavior is not consistent with the traditional either risk neutrality or expected-profit maximization. In a more recent experimental study comparing Chinese and American ordering policy differences, Feng et al. [16] finds the former being more consistent to the more traditional behavior. These last two studies underscore the need to introduce the concept of degree of risk tolerance and alternate optimizing objectives in the NVP formulation.

With respect to the degree of risk, Eeckhoudt et al. [14] and Agrawal and Seshadri [1] consider a risk-averse retailer who must choose the utility-maximizing price and quantity and compares the resulting policies to those of a risk-neutral retailer. However, in these models, the retailer has an opportunity to buy a second time, at a higher price, after realization of demand. This eliminates the risk of lost sales. Alternatively, Wang and Webster [36] study also the case of a risk-neutral manufacturer and a loss-averse retailer, without the second-purchase option, but with a buyback provision, that atones for the risk loss, while improving the profitability of both sides and of the chain as a whole. Chen et al. [10] considers also a risk-averse decision-maker, but within a multi-period framework. Ahmed et al. [2] drops the utility function criterion in favor of optimizing the worst-case expected profits or costs. In the process, this study shows that both the expected-utility and the worst-case approaches exhibit similar solution structures. Keren and Pliskin [21] use a linear utility function and a uniform demand distribution as a benchmark for more complex models. Wang and Webster [37] utilize a piecewise linear utility function and shortage costs to illustrate how the retailer's ordering policy may increase (decrease) in wholesale (retailer) price, the higher the shortage costs are and the higher the degree of risk aversion.

With respect to alternate objectives, the literature moved from the case of a risk-neutral retailer and price as a parameter and hence independent of demand. Current studies (e.g. [7,24–27,29,33,36–38,41–43]) search for the attainment of satisficing or, its equivalent, maximizing the probability of achieving target-oriented objectives on one or various performance measures. For example, Lin and Kroll [26] maximize the expected profit subject to a minimum probability of exceeding a fixed target profit. Parlar and Weng [29] maximize the probability of exceeding an endogenous target profit, namely the expected profit. Recently, Yang et al. [42] consider the maximization of the probability of achieving profit and revenue targets simultaneously, whereas Shi and Chen [33,34] develop Pareto-optimal contracts under multiple objectives, be them satisficing [34] or not [33]. In addition, [11,17] evaluate risk-averse solutions under the conditional value at-risk minimization criterion, whereas the mean–variance criterion is the objective of choice to analyze the NVP for [12,13,27,35,39,40].

To integrate into the NVP formulation the three characteristics just described, this paper evaluates analytically the main features of four different models. All four include a price dependent demand, incorporate the retailer's risk tolerance in different ways and embed different optimizing objectives. Objective 1 considers the maximization of the risk-adjusted expected profit of a retailer who may be risk-seeker, risk-neutral, or risk-averse. Objective 2 deals with a maximin strategy that maximizes a minimum guaranteed profit. The other two extend the formulations of [26,29] to include degrees of risk and price as decision variables. Numerical examples throughout the paper illustrate the main features of the models and provide some comparative policy analysis across the models. They also discuss additional regularities, not characterized as properties, because the complexity of the underlying mathematical structures renders impossible their analytical justification. A Conclusions section completes the paper. Finally, throughout the paper, the arguments of the variables and the asterisks to denote optimality are omitted whenever possible, to simplify notation.

2. Objective 1: maximizing the expected profit for a λ-risk retailer

The starting point of the model for objective 1 is the NVP formulation of [31] for a risk neutral retailer. The decision variables are the order size, Q and the unit selling price, p. The cost/revenue parameters include a unit cost of production/purchase of w, a salvage-value return of $v<w$ for any leftover and a penalty of s per shortage unit. There is a stochastic demand of $x(p)$ units composed of a price-dependent deterministic component of $g(p)$ units and a random component, ε. The deterministic demand function can take any form, as long as it is decreasing with p and twice differentiable. The error random variable, ε, is defined over a finite range $[A,B]$, with a mean of μ, a standard deviation of σ, a density function of $f(\varepsilon)$ and a cumulative distribution function of $F(\varepsilon)$. The interaction between the two demand components may be multiplicative or additive following the works of [20,28], respectively, with the former (latter) exhibiting a constant (variable) error variance and a variable (constant) coefficient of variation. Khouja [22], Lau [23], Petruzzi and Dada [31] and Yao et al. [43] discuss the implications of these assumptions. The profit function, $\Pi(p,Q)$, is expressed as follows:

$$\Pi(p,Q)=\begin{cases} x(p)p-Qw+[(Q-x(p)]v, & \text{for } Q\ge x(p)\\ Qp-Qw-[x(p)-Q)s, & \text{for } Q<x(p)\end{cases}$$

where

$$x(p)=\begin{cases} g(p)+\varepsilon, & \text{if additive error}\\ g(p)\varepsilon, & \text{if multiplicative error}\end{cases}$$

$$\text{and}\quad g(p)=\begin{cases} a-bp,\ a>0,\ b>0 & \text{for linear demand}\\ \alpha p^{-\beta},\ \alpha>0,\ \beta>1 & \text{for iso-elastic demand}\end{cases} \tag{1}$$

Observe that (1) includes linear and iso-elastic demand functions, with additive and multiplicative demand error structures. This gives rise to four different sets of pricing and ordering policies, when cross-classifying jointly $g(p)$ and $x(p)$. Following standard convention (e.g. [6,31]), we report in this paper only results, be they analytical or numerical, associated with linear-demand/additive-error (or *LA* demand case) or with iso-elastic-demand/multiplicative-error (or *IM* demand case). Also for simplicity and analytical tractability, the random error, ε, is uniformly distributed, with an error range of between $-u/2$ and $u/2$ ($\mu-u/2$ and $\mu+u/2$), for the additive (multiplicative) case, subject to the non-negative lower bound on demand. In addition, following also standard convention (e.g. [31]), we introduce the stocking level, z, as a decision variable,