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Would a risk-averse newsvendor order less at a higher selling price? ☆

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ABSTRACT

We model a risk-averse newsvendor's decision-making behavior with some commonly used classes of utility functions within the expected utility theory (EUT) framework. Under fairly general conditions of EUT, we show that a risk-averse newsvendor will order less than an arbitrarily small quantity as selling price gets larger if price is higher than a threshold value, i.e., the optimal order quantity decreases as the selling price increases.

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1. Introduction

Consider a newsvendor who must decide how many newspapers to order from the publisher in the morning for sale during the day. If he orders too few, he will lose potential sales and may also face additional shortage costs such as a loss of goodwill. If he orders too many, he must salvage all unsold newspapers to the publisher at a lower value. The newsvendor's objective is to choose an optimal order quantity to balance his cost (or disutility) of ordering too many against his cost (or disutility) of ordering too few. Because of its simple but elegant structure, the single-period newsvendor model has contributed insight to a variety of settings such as inventory control, capacity planning, yield management, insurance, and supply chain contracts.

The standard newsvendor problem is based upon risk neutrality so that managers will place orders to maximize expected profits. However, in practice, there are many examples that imply managers' decisions do not always correspond to the expected profit-maximization order quantity (e.g., Kahn, 1992; Fisher and Raman, 1996; Patsuris, 2001). Therefore, developing alternative choice models rather than risk neutrality to describe manager's newsvendor decision-making behavior is becoming more important. Within this research stream, some researchers have studied risk-averse newsvendor decisions within the expected utility theory (EUT)¹ framework (e.g., Eeckhoudt et al., 1995; Agrawal and Seshadri, 2000a,b).

Although those risk-averse newsvendor models provide useful guidance to managers on their optimal inventory decisions, none of them pay enough attention to a limitation of EUT in the economics field, i.e., *risk aversion within the EUT framework implies that people are approximately risk-neutral when economic stakes are small* (Arrow, 1971). For example, Rabin (2000) exposed some of the problematic consequences of this limitation for the question of whether or not to accept a gamble. His risk aversion calibration theorem shows that within EUT, even very little risk aversion over modest stakes implies an absurd degree of risk aversion over large stakes, e.g., if a person turns down gambles where she loses \$100 or gains \$110, each with 50% probability, at any wealth level, then she will turn down a 50–50 bet of losing \$1000 or gaining an infinite sum of money. That is an absurd rate for the utility of money to deteriorate, thus showing a limitation of risk aversion.

This paper is especially motivated by the following result we observed in a numerical study in Section 4:

Suppose a manager chooses a commonly used exponential utility function within EUT to describe his risk aversion newsvendor decision-making behavior. If demand is uniformly distributed between 0 and 100, then a slightly risk-averse manager will order 49 at unit cost \$100 if his selling price is \$400, but will order 47 if his selling price is \$600. In other words, the quantity that maximizes his

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¹ The EUT framework posits that risk neutrality, risk aversion, and risk taking are a consequence of a utility function over wealth that is linear, concave, and convex, respectively.

expected utility is 49 when the opportunity cost of a lost sale is only \$300, but when his opportunity cost is higher at \$500, his optimal order quantity decreases, and in fact, approaches zero as selling price continues to increase.

The above numerical example shows that as selling price becomes higher and higher, i.e., the prospect of selling a perishable product (e.g., newspaper) becomes better and better, a risk-averse manager prefers ordering less and less according to EUT. This anomalous result illustrates that the limitation of EUT also exists in the risk-averse newsvendor problem.

The main purpose of our research is to show when, how, and why the limitation of EUT noted by Arrow and Rabin is manifested in newsvendor decision-making. We use a series of theorems to characterize the relationship between a risk-averse newsvendor's optimal order quantity and selling price. For most commonly used classes of risk aversion utility functions within EUT, e.g., CARA, IARA, and bounded DARA utility functions², we find that a risk-averse newsvendor will order less than an arbitrarily small quantity as selling price gets larger if price is higher than a threshold value. Our results suggest that: (1) some care is in order when interpreting results based on newsvendor models and EUT, and (2) investigation of types of models suitable for risk-averse newsvendor behavior has merit.

This paper is organized as follows. In Section 2, we briefly review the relevant literature. In Section 3, we analyze the risk-averse newsvendor problem and derive some theorems and insights. In Section 4, we use a numerical example to illustrate our results. Finally, in Section 5, we offer concluding remarks and suggest opportunities for future research.

2. Related literature

The literature related to this research can be divided into two general categories: papers on the newsvendor problem with alternative utility functions to risk neutrality, and papers addressing limitations of EUT.

The traditional newsvendor model is based upon risk neutrality. We refer interested readers to [Porteus \(1990\)](#) and [Khouja \(1999\)](#) for reviews of this part of literature. Some researchers have attempted to use risk aversion within EUT to describe the decision-making behavior in the newsvendor problem. [Eeckhoudt et al. \(1995\)](#) study a risk-averse newsvendor who is allowed to obtain additional orders if demand is higher than his initial order. They find that a risk-averse newsvendor will order strictly less than a risk-neutral newsvendor. [Agrawal and Seshadri \(2000a\)](#) investigate a risk-averse and price-setting newsvendor problem. They find that a risk-averse newsvendor will charge a higher price and order less than the risk-neutral newsvendor if the demand distribution has the multiplicative form of relationship with price. Also, the risk-averse newsvendor will charge a lower price if the demand distribution has the additive form of relationship with price, but the effect on the quantity ordered depends on the demand sensitivity to selling price. [Agrawal and Seshadri \(2000b\)](#) consider an important role of intermediaries in supply chains to reduce the financial risk faced by risk-averse retailers. They show that a risk-neutral distributor can offer a menu of mutually beneficial contracts to the retailers so that the supply chain inefficiency due to risk-averse retailers can be avoided. [Keren and Pliskin \(2006\)](#) study a risk-averse newsvendor model under uniform demand. They derive the closed form solution and discuss its properties and application for assessing the newsvendor utility function parameters.

In addition to risk aversion, some researchers have used loss aversion within Prospect Theory ([Kahneman and Tversky, 1979](#)) to describe the decision-making behavior in the newsvendor problem. Loss aversion is distinguished from risk aversion by the presence of a reference point that determines whether a pay-off is perceived as a loss or a gain, and by an abrupt change in the slope of the utility function at the reference point. [Wang and Webster \(forthcoming\)](#) study a loss-averse newsvendor problem. They find that if shortage cost is not negligible, then a loss-averse newsvendor may order more than a risk-neutral newsvendor. They also show that a loss-averse newsvendor's optimal order quantity may increase in wholesale price and decrease in retail price, which can never occur in the risk-neutral newsvendor model. [Wang and Webster \(2007\)](#) consider a decentralized supply chain in which a single risk-neutral manufacturer is selling a perishable product to a single loss-averse retailer facing uncertain demand. They investigate the role of a gain/loss sharing provision for mitigating the loss aversion effect, which drives down the retailer order quantity and total supply chain profit.

We next briefly review research on EUT and its limitations. EUT may be traced back to [Bernoulli \(1954\)](#) in response to the famous St. Petersburg paradox.³ Later, the development of EUT with a set of appealing axioms on preference by [von Neumann and Morgenstern \(1944\)](#) provided the basis for most subsequent analysis of economic behavior under uncertainty. In particular, EUT allows for a bounded utility function, thus avoiding the St. Petersburg paradox. We refer to [Schoemaker \(1982\)](#) for a comprehensive review of EUT.

Although EUT is well accepted, empirical studies dating from the early 1950s (e.g., [Allais, 1953](#)) have shown some patterns in choice behavior inconsistent with EUT. The most recent paper reinforcing this theme is [Rabin \(2000\)](#), who characterizes a relationship between risk attitudes over small and large economic stakes. His calibration theorem applies to lotteries with two possible outcomes. He shows that within EUT, anything but virtual risk neutrality over modest stakes implies an absurd degree of risk aversion over large stakes. The results raise questions into validity of conclusions from experiments and analyses that rely on same utility function over large and small stakes. What is not clear is whether EUT presents any difficulties in a more complex newsvendor setting, a setting that can be viewed as a lottery with not two, but many possible outcomes contingent upon an order quantity. In addition, the choice is not whether or not to accept a gamble but how much to buy among a range of alternatives.

3. The risk-averse newsvendor model under EUT

We consider a risk-averse newsvendor with initial wealth W_0 selling short-life-cycle products with uncertain demand. At the beginning of the selling season, the newsvendor initially orders Q products at a unit cost w from a supplier and sells at a retail price $p > w$ during the selling season. Demand X is stochastic with PDF $f(x)$ and CDF $F(x)$ defined over the continuous interval $I = [a, b]$. To simplify notation, we

² Utility functions within EUT are commonly classified into three categories of absolute risk aversion: (1) *decreasing absolute risk aversion* (DARA), which states that as an individual becomes wealthier, he will be less risk-averse, (2) *increasing absolute risk aversion* (IARA), which states that as an individual becomes wealthier, he will be more risk-averse, and (3) *constant absolute risk aversion* (CARA), which states that an individual's degree of risk aversion is independent of his wealth level.

³ Suppose a utility function $U(\cdot)$ is unbounded (e.g., as is the case for a risk neutral utility function), so that for every integer n there is an amount of money x_n with $U(x_n) > 2^n$. Consider the following lottery: we toss a coin repeatedly until tails comes up. If this happens in the n th toss, then the monetary payoff from the lottery is x_n . Since the probability of this outcome is 2^{-n} , it is clear that the expected utility of this lottery is infinity. But this means that an individual should be willing to give up all his wealth for the opportunity to play this lottery, an absurd conclusion.

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