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## A loss averse competitive newsvendor problem with anchoring

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### ARTICLE INFO

#### Article history:

Received 12 April 2017

Accepted 10 October 2017

Available online xxx

#### Keywords:

Newsvendor problem

Loss aversion

Anchoring

Competition

### ABSTRACT

We study a loss averse competitive newsvendor problem with anchoring under prospect theory. We consider two demand-splitting rules for quantity competition, including proportional demand allocation and demand reallocation. We characterize the optimal order quantity decisions under both demand rules. We find that the newsvendor's order quantity is decreasing with the degree of loss aversion and the value of the anchor. Compared with an integrated risk-neutral supply chain, a positive anchor always leads to inventory understocking, whereas a negative anchor may result in a serious overstocking. Under competition with homogeneous newsvendors, competition always makes newsvendors order more, which does not necessarily lead to a loss of profit. For newsvendors with a high anchor, competition helps to prevent understocking caused by the anchoring effect, which leads to an increase in profit. For newsvendors with a low anchor, competition exacerbates overstocking, which results in a loss of profit. Under competition with heterogeneous newsvendors, a newsvendor with a higher degree of loss aversion or with a higher anchor adopts a more conservative strategy (i.e. choose a lower order quantity), which results in a smaller market share.

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### 1. Introduction

The newsvendor problem is a classic model in stochastic inventory management that has been widely used and analysed in operations management since the work of [1]. We refer interested readers to [2] and [3] for a detailed review of the newsvendor problem and its extensions.

In recent years, empirical investigations have shown that actual orders often deviate from the optimal order quantity of the risk-neutral newsvendor. Schweitzer & Cachon [4] explain the over-ordering/under-ordering pattern by relying on the risk attitudes towards gains and losses. They point out that prospect theory can explain the ordering bias because it shows that newsvendors are risk averse (seeking) when facing gains (loss) and, thus, should always under order (over order). According to the expected utility theory, individuals only care about absolute wealth, rather than relative wealth in any given situation. In contrast, prospect theory states that people are more sensitive to changes to an anchor (reference point) than they are to absolute changes, where the notion of an anchor was first introduced by Slovic [5]. According to Tver-

sky & Kahneman [6], the anchoring effect, as a cognitive bias, is the disproportionate influence on decision-makers to make judgments that are biased towards an initially presented value. Many studies have illustrated that the anchoring effect is prevalent in human decision-making in a variety of fields. We refer interested readers to Furnham & Boo [7] for detailed review of the anchoring effect.

Recently, Nagarajan & Shechter [8] confirmed that the newsvendor always under orders in the low-profit case and over orders in the high-profit case, under a certain prospect theory utility, which contradicts existing experimental results. Therefore, they claim that prospect theory cannot explain the ordering bias. However, Zhao & Geng [9] point out that the reason why prospect theory cannot explain this bias is that the utility function in Nagarajan & Shechter [8] misses a key feature, namely, an anchor. If an anchor is appropriately determined, then prospect theory can be used to explain the ordering bias. Furthermore, Ren & Croson [10] and Ren et al. [11] use experiments to show that the decision bias may be caused by overconfidence/over-precision when estimating the demand risk (with an inappropriate anchor). They also find that if the anchoring effect is considered, then prospect theory can explain the behavioural deviations in the newsvendor problem, without relying on risk preferences. However, most existing studies on the loss averse newsvendor problem under prospect theory are

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based on a zero anchor (zero payoff) and, thus, ignore the anchoring effect. How an anchor affects the optimal order quantity of a loss averse newsvendor, and whether such a newsvendor with an anchor benefits the supply chain remain unclear.

To fill these research gaps, we study the loss averse competitive newsvendor problem with anchoring under a piecewise loss averse utility function. Here, we use a target unit profit as an anchor, and consider quantity competition under both the demand-reallocation rule and the proportional demand-allocation rule. We prove that there exists a unique Nash equilibrium under both demand-splitting rules. Our results show that both loss aversion and anchoring decrease the newsvendor's order quantity. In particular, compared with an integrated risk-neutral supply chain, a positive anchor always leads to understocking for a loss averse monopoly newsvendor, while a negative anchor may lead to overstocking. For loss averse competitive newsvendors, a relatively high anchor always leads to inventory understocking. Both competition and a lower anchor can help counter this effect by having the newsvendor order more stock, which leads to an increase in profit and benefits the supply chain. However, as newsvendors lower their anchors furthermore, a relatively low anchor may lead to inventory overstocking, which results in a (significant) loss of profit. Since the anchor determines whether an outcome is perceived as a loss or a gain, our results stress that anchoring dominates loss aversion in reducing order quantities. Furthermore, we show that demand-splitting rules can affect the profits of competitive newsvendors. The profit gain in the demand reallocation is higher than that in the proportional demand allocation because only part of the demand is reallocated in the former case. Moreover, for heterogeneous newsvendors, a newsvendor that is more loss averse or that has a higher anchor is more conservative when ordering, which results in a smaller market share.

In summary, the contributions of this study to the existing literature on loss averse newsvendor models are threefold. First, although some studies (e.g. [12,13]) have considered the loss averse competitive newsvendor problem under a loss averse utility with a zero anchor, they ignore the anchoring effect, which may lead to incomplete and less rigorous conclusions. Therefore, we consider the loss averse competitive newsvendor problem with the anchoring effect, which has not yet been studied. Second, the related literature (e.g. [12]) has only explored quantity competition under a certain demand-splitting rule, namely, proportional demand allocation. How different splitting rules (proportional demand allocation vs demand reallocation) influence the equilibrium order quantity and the total profits of newsvendors has not yet been studied. Third, the prior studies on the loss averse competitive newsvendor problem assume that newsvendors are homogeneous (e.g. [12]). Therefore, the effect of heterogeneity on this problem is still unknown.

The remainder of this paper is organized as follows. In the next section, we review the literature on the loss averse newsvendor problem with anchoring, as well as the loss/risk-averse competitive newsvendor problems. Section 3 introduces the proposed model. Section 4 considers the competitive model under both the demand-reallocation rule and the proportional demand-allocation rule. Section 5 discusses the effect of loss aversion, anchoring, and competition, and presents our numerical results. Section 6 discusses the heterogeneous competitive newsvendor problem by means of numerical examples. Finally, Section 7 concludes the paper. All proofs are available in the appendix.

## 2. Literature review

We survey existing studies on the newsvendor problem, which follow two streams of research: anchoring and competition.

### 2.1. The loss averse newsvendor problem with anchoring

Based on the prospect theory established by Kahneman & Tversky [14], the loss averse newsvendor problem has attracted much attention in recent years. Schweitzer & Cachon [4] were the first to study this problem under prospect theory and to use an experiment to verify their results. Wang & Webster [15] study the newsvendor problem under loss averse utility with a zero anchor. Wang [12] and Liu et al. [13] extend their work to game settings under the proportional demand-allocation rule and by including production substitution, respectively. Ma et al. [16] study a loss averse newsvendor problem with uncertain supply under the same utility criterion used by Wang & Webster [15]. Using the same loss averse utility with a zero anchor, these studies all show that loss aversion always leads to a decrease in order quantity.

As a zero anchor is a special case in prospect theory, and the anchoring effect as a cognitive bias may significantly affect people's decisions, some researchers study how an exogenous (nonzero) anchor affects the order quantity of a loss averse newsvendor. Herweg [17] points out that a newsvendor's order quantity depends heavily on the selected anchors. He shows that loss averse newsvendor with a given exogenous anchor always orders less than the risk-neutral newsvendor does. If the value of the anchor is extremely high or low, then loss aversion plays no role. Long & Nasiry [18] study a similar loss averse newsvendor problem with a nonzero anchor. They also find that, for certain anchors, the anchoring effect can explain the newsvendor's ordering behaviour, without needing to incorporate the newsvendor's attitude to risk or loss. Furthermore, they show that a newsvendor with a sufficiently low anchor may order more stock.

### 2.2. The competitive newsvendor problem

The competitive newsvendor problem has been studied under different risk criteria. For risk-neutral newsvendors, Parlar [19] first studies the risk-neutral newsvendor problem under quantity competition, in which two substitutable products are sold to two identical newsvendors. [20] study a competitive newsvendor problem with a single product, in which random demand is allocated among competing newsvendors with certain demand-splitting rules. Cachon [21] considers the same problem with a proportional demand-allocation rule; that is, the supplier allocates demand among the newsvendors in proportion to their orders. These studies all find that quantity competition always leads to overstocking and a loss of profit. For risk-averse newsvendor, Wu et al. [22] investigate the risk-averse newsvendor problem with quantity competition and price competition under the CVaR criterion. By considering both the proportional demand-allocation rule and the demand-reallocation rule, they show that quantity competition does not necessarily lead to a loss of profit in certain competitive environments when newsvendors are risk averse. For loss averse newsvendors, based on prospect theory and under the proportional demand-allocation rule, Wang [12] extends the classic competitive newsvendor problem to a game setting in which newsvendors are loss averse. Using the same utility criterion as in [12] and under the demand-reallocation rule, Liu et al. [13] study the loss averse competitive newsvendor problem with production substitution. Both studies show that loss aversion always leads to a decrease in total order quantities of all newsvendors, and may lead to supply chain understocking.

To the best of our knowledge, existing studies on the anchoring effect are based on the loss averse newsvendor problem in which there is only a monopoly vendor in the market. Furthermore, studies on loss averse competitive newsvendor problems are based on a certain demand-splitting rule. Some interesting and unexplored questions are as follows. *How does the joint effect of loss aversion,*

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