Modeling Newsvendor Behavior: A Prospect Theory Approach

1. Introduction

The newsvendor model is at the core of inventory and supply chain management. It has been used extensively in the design of optimal inventory systems and supply chain contracts. Most of the literature on these topics assumes that the newsvendor is either an expected profit–maximizing agent or a risk-averse agent. However, experimental studies have shown that the behavior of subjects in newsvendor experiments is not consistent with these models. In their seminal paper, Schweitzer and Cachon (2000) identified the existence of a pull-to-center (PTC) effect in newsvendor decisions: for products with high (resp., low) profit margins, the average order quantity is greater (resp., less) than the mean demand but less (resp., greater) than the expected profit–maximizing quantity. This effect has been consistently replicated in subsequent experiments. Although the PTC effect was observed in these experiments at the aggregate level, research thereafter assumed that it is a characteristic property of individual-level behavior (for a review of this literature, see Lau et al. 2014). Based on this assumption, several models have been proposed that explain the PTC effect; models that do not predict the PTC effect are deemed incapable of explaining the newsvendor behavior.

Lau et al. (2014) challenge the assumption that individual behavior exhibits a pull-to-center effect. These authors show that there is remarkable heterogeneity in the order quantities, and the behavior of a significant proportion of subjects is inconsistent with the pull-to-center effect. We must consequently bear in mind that a model should not be accepted as representing newsvendor behavior, or rejected as being unrepresentative, based solely on the PTC effect. Any model that plausibly represents newsvendor behavior should predict the existence – under both low- and high-margin settings – of individuals who exhibit the pull-to-center effect (i.e., who order quantities inside the PTC zone) and of individuals who do not exhibit this effect (i.e., who order quantities outside the PTC zone). We argue that the models in the extant literature cannot predict this heterogeneity and are inconsistent with certain observed empirical regularities.

Designing effective supply chain processes and inventory systems requires that the underlying models represent the observed newsvendor behavior reasonably well, especially in settings where most decisions are made by individuals. However, using the extant models for analysis ignores the behavior of a significant proportion of the population, which, therefore, necessitates building models that better represent newsvendor behavior. This paper builds models that can consistently predict pull-to-center effect across both low- and high-margin settings and that also accommodate individuals who do not exhibit the PTC effect. It also evaluates the competence of these models in representing the observed newsvendor behavior. We build these models based on prospect theory (Kahneman and Tversky 1979, Tversky and Kahneman 1992) and its extensions.
2. Methodology

Prospect theory (PT) is a well-established descriptive theory of decision making that has been used to explain several phenomena of interest in various fields. This theory incorporates two important features of human behavior: reference dependence and loss aversion. By considering zero profit as the reference point, Schweitzer and Cachon (2000) argue that PT cannot predict the pull-to-center effect. However, Long and Nasiry (2015) show that if the reference point for an order quantity is assumed to be the “weighted average of the maximum and minimum profits that could be obtained with that quantity”, then the resultant model can predict the PTC effect. The important contribution of the Long and Nasiry study is that it highlights the central role played by the reference point in predicting newsvendor behavior.

However, Long and Nasiry’s model relies on an arbitrarily chosen reference point, which is neither theoretically motivated nor empirically validated. Given that reference point is crucial in a prospect theory model, a rigorous evaluation of their model along with other plausible PT models is needed to determine its appropriateness in representing the observed newsvendor behavior. In this paper, we take a more comprehensive approach in building and evaluating PT models. In theory, there are an infinite number of possible reference points. So following Kahneman’s (1992) argument that a reference point is a salient point within an individual’s cognitive norm, we choose to evaluate some salient reference points in newsvendor experiments as the candidates. We consider three fixed reference points (the minimum payoff, the maximum payoff, and the sure-shot payoff in the newsvendor experiment), three stochastic reference points (minimum demand, maximum demand, and mean demand) and two prospect-dependent reference points (disappointment model of Bell 1985, and the model of Long and Nasiry 2015). Thereafter, we evaluate these models to determine the most appropriate model.

Even though more than three decades have passed since prospect theory was developed, there is still no concrete theory on how reference points are formed and updated (Barberis 2013). Inspired by several different methods used in the existing research to evaluate reference-dependent models, we use a multipronged approach to analyze our candidate models: First, we examine if the models have some theoretically appealing criteria (e.g., model should predict heterogeneity in newsvendor behavior, it should do so as parsimoniously as possible, and should lead to credible predictions in certain extreme parameter settings). Second, using likelihood-based method, we evaluate the quality of the fit of these models to the actual heterogeneity in the experimental data (obtained from existing studies). Third, we identify certain empirical regularities in the newsvendor experiments which can be validated against the predictions of the competing models.

3. Results

The model of Long and Nasiry (2015), surprisingly, falls short on almost all theoretical and empirical criteria as compared to other models discussed in our paper. We show that this model yields several unrealistic predictions in the newsvendor context largely because of the quantity dependence of its reference point. Moreover, its fit to data is inferior to some competing models, and it cannot consistently predict certain empirical regularities observed in the newsvendor experiments.

Although the predictive performance of other models varies across data sets, the model with mean demand as reference point consistently outperforms those other models by as much as a 20% improvement (i.e.,
reduction in prediction error) over competing models. It is noteworthy that this model also explains two consistent observations at the aggregate level: for the aggregate data, the modal order quantity tends to be mean demand whereas the mean order quantity tends to lie in the PTC zone. Moreover, all the empirical regularities considered in our paper are consistent only with this model. This suggests that mean demand is more likely to be adopted by experimental subjects as a reference point – perhaps because, in large part, mean demand is more salient than the other plausible reference points mentioned. We then extrapolate our insights from lab experiments to the retail industry in emerging markets, where we conjecture that the model with mean demand as reference point might reasonably represent the behavior of human retailers, and use it to identify settings in which retailers could benefit from investing in decision support systems.

Our paper makes three main contributions. First, we highlight the limitations of currently employed models and the importance of accommodating heterogeneity in newsvendor behavior, after which we build PT models that predict heterogeneity. Second, we use several theoretical and empirical criteria to test the relative performance of these models, and then adopt the model most likely to derive some empirically consistent predictions and prescriptive insights. Third, the models discussed in this paper emphasize the importance of accounting for loss aversion and reference dependence in the newsvendor scenario. These concepts have been successfully applied by economists in several contexts, but they have yet to penetrate the OM literature. The approach we take can serve as a template for identifying and selecting appropriate models with loss aversion and reference dependence – and, it is hoped, thus increasing their application in the OM literature.

References