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Teaching the Newsvendor Model Using Spreadsheet Models

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Abstract. The newsvendor model is one of the most important and popular teaching topics for operations and supply chain management classes. The optimal solution for this model is a closed-form that uses the critical fractile which can be a sort of customer service level (CSL) and rounding-up rule. Students who lacked quantitative skills were not able to understand the meaning of critical fractile to calculate the expected profit. Using this teaching brief, however, students got a better sense of the concept that both cost structure and demand pattern affect the optimal solution by testing the combinations of three demand patterns (i.e., symmetric, right-skewed, and left-skewed) and three cost structure cases (i.e., underage cost = overage cost, underage cost > overage cost, and underage cost < overage cost) numerically. Using this scenario-based approach, instructors can better relate the insights gained from the numerical study to the newsvendor solution. Instructors can then more easily show students how to compute the optimal order quantity and its related expected profit using spreadsheet models. When CSL, defined by the probability of satisfying demand, is given, students can find the corresponding order quantity and its expected profit. For any offered order quantity, students were able to get CSL as well as determine the expected profit. Students need to understand the relationships between order quantity, CSL, and the expected profit. Comparative studies for successive semesters demonstrated the effectiveness of our approach, as students' quiz performance significantly improved, resulting in final letter grade improvement.

Keywords: newsvendor, customer service level, cost structure, demand, distribution, spreadsheet model.

1. Introduction

The newsvendor model is a fundamental teaching and research topic in operations and supply chain management (Silver and Peterson 1985, Silver *et al.* 2017, Cachon and Terwiesch 2004, Nahmias 2008, Chopra and Meindl 2014, Jacobs and Chase 2014, Cachon and Terwiesch 2016, Stevenson 2018). The basic assumptions for this model are relevant to the real-world environment, i.e., (i) uncertain demand; (ii) one-time selling season; and (iii) decision should be made before demand is realized. Van Woensel *et al.* (2010) show that it is hard for students who lack quantitative literacy skills to catch up to the theoretical results directly and gain the proper insights they need from them. We also find that such students could neither understand the optimality concept and its solution (i.e., critical fractile) clearly, nor determine the precise relationship between critical fractile, customer service level (CSL), and the related order quantity. Therefore, we suggest this teaching brief as a tool to address the newsvendor model in a more meaningful and easily understood manner.

Textbooks (Silver and Peterson 1985, Silver *et al.* 2017, Cachon and Terwiesch 2004, Nahmias 2008, Chopra and Meindl 2014, Jacobs and Chase 2014, Cachon and Terwiesch 2016, Stevenson 2018, Krajewski *et al.* 2018), certain Harvard Business School cases (Narayanan and Brem 2003, Narayanan and Raman 2015), and other related teaching cases (Raz 2013, Surti and Celanti 2019) address newsvendor models using good examples. Each presumes a specific demand distribution. Chopra and Meindl (2014), Cachon and Terwiesch (2004), and Nahmias (2008) show detailed proof of optimality and explain that the critical fractile is determined by the price and cost factors. The optimality concepts can also be better explained through spreadsheet modeling and visualization (Kulkarni *et al.* 2019). Kulkarni (2011) demonstrates an interactive visual tool for the newsvendor model for normal distribution. Other inventory models have been taught using spreadsheet modeling (Cobb 2013, Strakos 2016, Liu *et al.* 2013). The current teaching brief covers both symmetric (e.g., normal, uniform) and non-symmetric demand distributions (e.g., Poisson, empirical) and offers spreadsheet models for several demand distributions.

Not only textbooks but also several pedagogical papers have focused on how to deliver knowledge for the most effective classroom teaching. Pfeifer et al. (2001) address three approaches for teaching the newsvendor model in the classroom, namely, the decision tree, the spreadsheet model, and an analytical critical fractile. Pfeifer *et al.* (2001) discuss the strengths and difficulties of each approach and favor the spreadsheet model, but do not present as many details as this note. Netessine and Shumsky (2002) note the parallels between yield management and the newsvendor framework, while Choi and Ketzenberg (2018) address an inverse newsvendor model to determine the optimal demand size given fixed capacity. Surti and Celanti (2019) relate Prospect Theory to the behavioral perspective during the newsvendor decision-making process and then use active learning during classroom discussions.

Researchers have devised experimental designs about the decision-making process to explain how business managers make their inventory decisions. Schweitzer and Cachon (2000) explain the managers' decisions by using various patterns of choice, showing that decision-makers might have preferences other than making profit-maximizing inventory decisions. Schweitzer and Cachon (2000) introduce the so-called pull-to-center bias. Orders for high-profit products, for which the critical fractile is greater than 0.5 (or median), are lower than the optimal solution, while orders for low-profit products, for which the critical fractile is less than 0.5, are higher than the optimal solution. Bostian *et al.* (2008) replicate Schweitzer and Cachon

(2000)'s experiment and construct an adaptive learning model that incorporates memory, reinforcement, and probabilistic choice and thereby is able to explain the individual decisions. The subjects in the experimental studies have been given a single demand scenario for each round that is independent of the previous round. Benzion *et al.* (2008) show that the subjects are affected by their previous round experience and thus learn that past information is not relevant to their current decision-making choices. The experimental studies recruit their subjects from academia (Schweitzer and Cachon 2000, Bostian *et al.* 2008, Benzion *et al.* 2008, Gavirneni and Isen 2010, Feng and Gao 2020, Surti and Celanti 2019, Kwak 2015) or business (Bolton *et al.* 2012). Bolton *et al.* (2012) find that both students and managers behave similarly by demonstrating the pull-to-center bias. It is disconcerting that knowing the theory does not help people choose the best solution because most subjects in the experimental studies have an educational experience in the newsvendor model. This teaching brief may thus help instructors remove the pull-to-center bias by addressing the impacts of the demand shape and the cost factor.

Yet another research stream focuses on the cognitive process of decision-making, not the pattern of the choices made. Gavirneni and Isen (2010) capture the decision-making thought process by using verbal protocol analysis. They find that most subjects are able to compute overage and underage costs, but fail to associate those costs with the demand to determine the optimal inventory decision. Kwak (2015) repeats Gavirneni and Isen (2010)'s experiment under different language and culture conditions, and show that differences do exist between American, Chinese, and Korean students and further that a wrong inventory decision results from the pull-to-center bias and a general lack of knowledge of probabilistic concepts. Feng and Gao (2020) further explain that optimal recommendations suggested by a decision support system may not always be the best for managerial decision-making, given the uncertainties because of algorithm and regret aversions.

Here we thus concentrate on how students or business managers can specifically improve their understanding of the newsvendor model rather than only the decision-making process. In the classroom, we assume that newsvendors have good knowledge about demand distribution and do know how to obtain the optimal solution to guarantee to maximize the expected profit. The optimal solution cannot simply guarantee the best profit for each realized demand (i.e., each round) in the experiment such as Schweitzer and Cachon (2000) and Benzion *et al.* (2008) suggest. The newsvendors as the subject, are experiencing either leftover or stockout for every round. They perhaps, therefore, make their decisions based on previous round demand, not demand distribution parameters such as mean and variance. In other words, the subjects tend to over-react to short-term fluctuation (i.e., the law of small number bias suggested by Bolton and Katok (2008)) rather than exercising their long-term judgment. The newsvendors in such experiments are affected by the realized demand history, not the demand distribution itself. Bolton *et al.* (2012) emphasize the importance of classroom experience and on-the-spot training and suggest providing expected profit information, a choice that is consistent with unbiasing the psychological and reducing computation errors. Bolton and Katok (2008) also stress the importance of knowledge through personal experience and a long-term focus. Spreadsheet models allow students to see variants, whereas experimental settings urge their subjects to see single incidents and hold a myopic view so that henceforth the pull-to-center bias can be enforced.

We have three main pedagogical goals and contributions to offer the community. First, we suggest an easier and more effective way to teach the newsvendor model in the classroom. Cost structure and demand shape are major determinants of this specific newsvendor solution. We numerically test the newsvendor model using discrete scenarios that consist of cost structure and demand shape. Our approach clearly demonstrates how demand shape affects the optimal solution. Other researchers (Schweitzer and Cachon 2000, Benzion *et al.* 2008, Bostian *et al.* 2008, Bolton *et al.* 2012, Surti and Celanti 2019) have used symmetric distributions, such as uniform and/or normal distributions where mean and median are the same. We further suggest an experiential learning idea to let students understand all the structural properties, not just the optimal solution for the newsvendor model. We find that students learn better and that more students gain a concrete understanding of the optimality when they are using the proposed experiential learning process in the classroom.

Secondly, we provide spreadsheet models for discrete and normal distributions to give students an opportunity to improve their spreadsheet modeling skills. Spreadsheet models for general discrete (or empirical), Poisson, continuous uniform, and lognormal distributions are also provided in the Appendix because they appear in textbooks. The first spreadsheet model uses simple formulae to show the expected profit for a single discrete order. The second spreadsheet model provides the expected profits for all possible discrete orders at the same time. Normal distribution spreadsheet model shows the step-by-step formulae that can be used to compute the expected profit and CSL. Students can also learn how to build spreadsheet models if time is allowed. Instructors may decide to cover additional spreadsheet models depending on students' modeling experience. Students will thus become flexible and confident at modeling through having this experiential learning opportunity.

Last, but certainly not least, we recommend that instructors provide students with an integrative perspective to relate order quantity, CSL, and expected profit. The traditional newsvendor model seeks to maximize expected profit internally. Most textbooks explain how to get the critical fractile and how to compute its expected profit, which is optimal. Cachon and Terwiesch (2004), Chopra and Meindl (2014), and Cachon and Terwiesch

(2016) address both the profit-maximization approach and another approach that is suggested by an arbitrary CSL. The customer-satisfaction approach sets CSL first and then computes its expected profit, which cannot guarantee an optimal outcome. It is difficult to identify the implicit cost of understocking, e.g., the cost of ill will or the loss of future business. Business managers may be more comfortable using CSL. In addition, we provide a quantity-based approach that allows business managers to test various quantity options by trial and error. We then let students discuss the three different perspectives. In so doing, we notice that many students thought of the profit-maximization and customer-satisfaction approaches as equivalent ones before we discussed this topic and that students learn how to acknowledge the difference between the two perspectives when we adopt the new approach.

The remainder of this paper is organized as follows. Section 2 explains the fundamental and well-known findings for the newsvendor model. Section 3 provides instructors with classroom activities so students will understand the concept fully. We also provide instructors with a teaching brief to address the newsvendor model in a more meaningful instructional way. Section 4 discusses the teaching effectiveness after we introduced the new approach. Section 5 concludes the paper with a discussion and final thoughts.

2. Modeling and Solving the Newsvendor Model

Every morning a newsvendor has to display newspapers on a newsstand for customers, given that the newsvendor already placed orders with the newspaper company the prior night. If the newsvendor orders too many papers, there will be leftover newspapers that lose value and can only be salvaged by a paper-recycling company. If the newsvendor orders too few papers, then the newsvendor may lose opportunities to make more money. Thus, it is important to optimize the order quantity by maximizing the expected profit, i.e., *revenue* − *cost* + *salvage*. Note that the revenue and salvage values are only measured at the end of the current selling season and the cost value before the selling season, respectively.

The newsvendor is supposed to know a probability distribution for the demand, which can be historical. In other words, demand distribution is random, but its distribution parameters (e.g., mean, median, and variance) are known. The newsvendor thus will place an order before the selling season and receive that order before (or as soon as) the selling season starts. The newsvendor has only a single selling season, i.e., the newsvendor has one-time demand and no additional demand to address after that selling season. These basic assumptions are relevant to the real practice of the newsvendor model. Seasonal (e.g., fashions) or perishable products (e.g., fish, flowers) are good examples of this newsvendor model. Promotional (e.g., Super Bowl) or holiday-related (e.g., Christmas, Halloween) products are also considered newsvendor models because their selling seasons involve only a one-time