

Behavioral Insights to the Newsvendor Model: A Brief Survey¹

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Abstract

Over the last 25 years, with various case studies and experimental studies, it is now well established that human decision-makers diverge from the theory when they are making economic decisions in operations management contexts. Owing to its simplicity and flexibility to be applicable to a wide range of business applications, the newsvendor model is the most popular inventory model used in operations management. Hence over the last 2.5 decades many researchers studied newsvendor behavior. In this chapter we present a brief review of the experimental behavioral operations studies that investigate human decision-making behavior in the newsvendor model.

1. Introduction

To paraphrase a former Turkish minister, recent years have seen a rise in the heterodox approach which represents an epistemological deviation from the neo-classical economic thought, especially with the increasing popularity of behavioral and neuro economics. In other words, scientists have started to question and test the existing theories of basic economic behavior as field experiments, case studies and laboratory experiments have shown that the theoretical expectations do not work in practice.

A derivative of experimental economics is behavioral operations management. This field focuses on human behavior in operations management scenarios and aims to test and identify factors that affect human decisions. The field has been around since mid-20th century with the multi-echelon supply chain distribution experiments, or in other words the

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beer distribution experiments to investigate the dynamics of the “bullwhip effect”. However, the field gained significant momentum and popularity only after the experimental study of Schweitzer and Cachon (2000). In this paper the authors conducted a simple newsvendor experiment in which the subjects were supposed to make consecutive ordering decisions. Their findings showed that there are systematic deviations in the order decisions from the optimal that cannot be explained by the existing theories based on risk aversion, loss aversion or prospect theory. After this paper many scientists focused their attention on conducting newsvendor experiments and unraveling the mystery of the deviations from the normative order quantity. In this chapter we aim to review these studies.

2. The Newsvendor Model

The newsvendor model is one of the fundamental models of supply chain management. This model is based on a single decision-maker determining the stock quantity of a perishable product facing a stochastic demand. Any leftovers at the end of the selling season lose their value and any unmet demand is lost. The decision-maker has only one ordering opportunity and the ordering must be done before the selling season starts and the demand is realized. So, there is a trade-off of ordering too much and having leftovers or ordering too little and losing potential profit. Along with this trade-off structure the newsvendor model is very intuitive which can be communicated to anyone without requiring an advanced degree.

The model also has a very elegant, simple solution which is very easy to calculate and use. The optimal solution to the problem is computed using the costs associated with ordering too much and too little. Specifically, if c_o is the cost of having ordered 1 unit more than the demand and, c_u is the cost of having ordered 1 unit less than the demand, and assuming the demand has cumulative distribution $F(\cdot)$, the optimal order quantity can be computed as:

$$Q^* = F^{-1}\left(\frac{c_u}{c_u + c_o}\right)$$

Additionally, many other problem contexts which has a similar trade-off structure, such as revenue management, operating room scheduling, etc., can be modeled as a newsvendor problem and the newsvendor solution can be applied to the solution of these problems. Furthermore, the model is also important as it is used in building larger, more complex supply chain management theories.

All these make the newsvendor model extremely powerful and important and that is why many researchers conducted experiments to investigate why human decisions deviated from the optimal and what factors caused this deviation.

3. Newsvendor Experiments

The start of the laboratory experiments involving a newsvendor setting can be traced back to the seminal study of Schweitzer and Cachon in 2000. The duo conducted two experimental studies with their students, resulting in the revelation of consistent deviations from optimal order quantities. These deviations were observed in both gain and loss domains, showcasing a remarkable consistency that puzzled existing behavioral theories. The authors discovered a persistent “too low too high” pattern in order decisions. That is, they observed that participants consistently ordered insufficient quantities when the purchasing cost was low or equivalently the profit margin was high, but tended to overstock when the situation is the opposite. Essentially, when the optimal amount to order was high due to a favorable profit margin, individuals ordered less than they should have. Conversely, when the optimal amount was low, individuals ordered more than necessary. This pattern resembled a pulling effect, with order decisions being drawn towards the center of the demand distribution. As a result, the phenomenon was named the “pull-to-center effect” by the authors.

The authors tried to explain the suboptimal order decisions with risk aversion. However, although successful in explaining below-optimal orders in high-profit situations, risk aversion couldn't explain the tendency to overstock in low-profit scenarios. Other well-established theories, including loss aversion, waste aversion, stock-out aversion, and underestimating opportunity costs all fell short in fully explaining this consistent pattern in the order decisions. Furthermore, although some evidence suggested the use of decision-making heuristics like mean anchoring and demand chasing, these explanations only partly addressed the observed deviations, leaving a mystery that required further investigation.

These intriguing findings inspired many other researchers to dive deeper into the newsvendor behavior trying to find the answers to the below questions:

- What are the core determinants behind these consistent divergences from optimality?
- Which factors dictated the extent and direction of these deviations?

- Can we identify and incorporate the underlying factors that led to this subpar performance into current theories?

Next, we will review the newsvendor studies in terms of their focus, subject pool and methodology.

3.1 Decision Biases

Bias refers to a tendency towards a particular perspective, possibly ignoring equally valid alternatives. Decision biases play a crucial role in the decision-making process of individuals. For instance, a fear of risk might lead someone to choose less risky outcomes, even if there are potentially better options available. These decision biases have a significant influence on how newsvendor decisions are made. Some of the commonly studied decision biases in newsvendor studies are summarized below.

Bounded Rationality

In standard economic theory, the decision-makers are assumed to be fully rational. That is, the theory assumes that when decision-makers are faced with several alternatives, they can easily compare these alternatives and select the one with the highest utility. A rational decision-maker not only is aware of what is best for her, but also is able to act upon this knowledge. Standard operations management theories subscribe to these assumptions, also.

However, in the light of recent studies, it is clear that the decision-makers are not always fully rational. At this point the term “bounded rationality” comes to stage. This term means that the decision-maker will choose the option with the highest utility not with certainty but with some probability. This is not due to the decision-maker being irrational, but rather due to cognitive limitations, limited memory, or other constraints on their decision-making processes. This is called “bounded rationality”. By using a quantal choice model, Su (2008) studies bounded rationality and through this explains the pull-to-center effect on the order decisions.

Prospect Theory

Prospect Theory explains how people behave under different conditions. For example, a person may tend to shy away from risk if they have a lot to lose but become more risk seeking if they have a small amount of wealth. This theory may explain the pull-to-center effect in newsvendor decisions. Although Schweitzer and Cachon (2000) after testing the prospect theory in their second experimental study, conclude that prospect theory fails to explain newsvendor behavior, there are several studies that claim otherwise.

Surti et al. (2020) is one of those studies demonstrating that newsvendor decisions can be explained through prospect theory.

Loss Aversion

Loss aversion is the bias of attaching greater weight to losses than gains. This bias is explored by Wang and Webster (2009) in a newsvendor setting where opportunity cost is significantly high. The study concludes that under these settings a loss-averse individual tends to stock more compared to a risk-neutral individual.

3.2 Decision Heuristics

Decision heuristics are techniques that people use to solve problems based on their past experiences using simple rule-of-thumb methods. In our context, decision heuristics refer to strategies that decision-makers utilize when making ordering decisions. The most prevalent heuristics in behavioral operations studies are anchoring and adjustments heuristics, demand chasing, and minimizing ex-post inventory error.

Anchoring and Adjustment Heuristics:

This heuristic involves the decision-maker anchoring their decisions at a reference point and making corrections towards the optimal. An example of this is the mean anchor heuristic, where the average demand is used as the initial reference point for the order quantities and then the orders are modified towards the optimal. Another example is the demand chasing heuristic, which uses the most recent order decision as anchor point and make corrections towards the most recent demand realization as if to chase the demand.

Gavirneni and Xia (2009) study anchoring behavior by offering an array of reference points to the decision-makers. Their study reveals that decision-makers choose the reference point which is closest to the optimal. Kremer et al. (2010) consider explaining newsvendor decisions through random errors and find that newsvendor decisions are strongly affected by mean anchoring, demand chasing and inventory error minimization heuristics. Lau and Bearden (2013) and Lau et al. (2014) study the mean anchor and demand chasing heuristics using data from several studies.

3.3. Learning Effect

A key question surrounding the newsvendor experiments is whether experience can improve performance. Many of the studies such as Schweitzer and Cachon (2000) and Schultz et al. (2018), Akbay (2016) test and do not

observe much of a learning effect on the ordering decisions. However, these studies are based on 30-40 decision rounds. 40 rounds of experience may not be sufficient to cultivate significant learning. As a matter of fact, the study conducted by Bolton and Katok (2008) uses 100 decision rounds and observes improvement in the order decisions over time.

3.4 The Impact of Feedback

In any context, receiving feedback after performing a task has a significant impact on future performance. As such, feedback about the ordering decisions has a significant impact on the ordering decisions. In this context, decision feedback has several aspects. One aspect is the feedback frequency which is investigated by Bolton & Katok (2008), and Lurie & Swaminathan (2009). Both studies manipulated the feedback frequency by having the order decisions to be effective for several rounds which is equivalent to the decision-makers receiving feedback about demand realizations and the performance of their order decisions less frequently. These studies reveal that frequent feedback does not necessarily improve decision performance. On the contrary, too frequent feedback can lead to worsened outcomes. However, too infrequent feedback also has negative effects on the performance. Bolton and Katok (2008) also investigate the effect of reinforced feedback by providing the decision-makers with information regarding the counterfactual payoffs associated with unchosen options. Their study reveals that this counterfactual payoff information has minimal impact on the quality of the order decisions.

3.5 Set of Decision Options

In most of the newsvendor experiments, the order quantity decision set is just restricted by the upper and lower limit of the demand distribution. That is within the demand range, the decision-makers are free to choose any integer. Questioning whether this wide array of options coupled with the bounded capabilities of the decision-makers is one of the reasons behind the suboptimal ordering decisions, Bolton and Katok (2008) manipulate the number of options available for order decisions. They restrict the decision set to a limited number of options hoping this will improve the newsvendor performance. Nevertheless, they do not observe any significant improvements. In a follow-up study Feng et al. (2011) also restricted the number of decision options but unlike Bolton and Katok, they made sure that the optimal order quantity is not an extreme point among the decision alternatives. This study shows significant performance improvements. This suggests that the result obtained by Bolton and Katok is not significant due

to the optimal order being an extreme point and the inherent extremeness-aversion in decision-makers.

3.6 Experiment Subjects

Experiment subjects are an essential part of the newsvendor experiments. Most studies use university students as subjects as conducting experiments with actual managers is usually extremely difficult and costly compared to the student body of the universities. Then arises the question of external validity of the experiments conducted with students. To address this concern, Bolton et al. (2012) conducted a study comparing the newsvendor performance of managers and students. Their study shows that when the demand distribution is provided there is no significant difference between the two subject groups indicating that students can be used as proxies for managers in newsvendor experiments. Moreover, there are experimental studies that are conducted with the general population rather than students and these studies confirm the earlier findings of studies done with students. One such study is de Vericourt et al. (2013), they conduct their experiments on MTürk.

Gender Differences

De Vericourt et al. (2013) investigate the effect of gender on newsvendor decisions and show that women make smaller order decisions owing to having higher risk-aversion. Akbay (2016) also studies gender differences in newsvendor behavior and finds female order decisions are smaller under high profit margin. The author also shows that female subjects are more prone to decision heuristics.

Cultural Differences

In newsvendor context, the number of cross-cultural studies is limited. Feng et al. (2011), Cui et al. (2013), Li et al. (2019) compare American decision-makers with Chinese decision-makers. Feng et al. (2011) find that the Chinese decisions are affected by the Doctrine of the Mean and are closer to the mean of the demand distribution implying that the Chinese decision-makers are more prone to the pull-to-center effect. Cui et al. (2013) finds somewhat similar and somewhat contradictory results. They show that the Chinese ask more questions signaling a higher error-aversion, and anchoring behavior is more prevalent in the American subjects. Li et al. (2019) find results parallel to Feng et al. (2011). They show that demand chasing, and mean anchor heuristics are more salient in Chinese decisions. However, they attribute this result to differences in cognitive abilities. Kwak (2015) compare Korean, Chinese, and American subjects and find that decision

heuristics are more prevalent in Korean subjects. Finally, Akbay (2022) compare Turkish and American subjects under buyback and revenue sharing settings. The author shows that under both settings both American and Turkish subjects make less than optimal decisions. Also, the order decisions under the revenue sharing setting are smaller than the orders under the buyback setting, implying that the framing of these settings affects order decisions. Finally, this study shows that demand chasing behavior is more salient in Turkish subjects.

3.7 Personality Traits

Experimental economics studies have established that there is a significant connection between personality traits and the economic decisions of individuals. There are several newsvendor behavior studies which investigate the connection between the newsvendor orders and personality traits. Moritz et al. (2013) study the effect of cognitive reflection and show that higher cognitive abilities translate to better newsvendor performance. Ren and Croson (2013) study overconfidence in newsvendor orders. Stohhecker and Größler (2013) show that the personality of the subject weakly affects the order performance. Akbay (2016) considers the effect of several personality traits and finds that subjects with lower self-esteem place smaller orders, and subjects with higher regret aversion place orders close to the mean of the demand distribution. However, these effects are not symmetrical under high and low profit margins. Akbay (2022) investigates the correlation between Hexaco personality traits and shows that subjects with higher emotionality score display higher demand chasing tendency.

3.8 Demand Distribution

Most of the newsvendor experiment studies consider a uniform distribution as it is the most intuitive demand distribution that can be explained easily. Benzion et al. (2008) explores the effect of demand distribution by using a normal distribution but finds no improvement in newsvendor performance.

Again, in most studies the demand realizations are fully revealed to the participants. Nevertheless, in a more realistic setting the decision-maker cannot know the excess part of the demand. That is if the demand exceeds the stock quantity, the lost demand will be censored to the decision-maker except the fact that the demand exceeded the stock quantity. Rudi and Drake (2014) consider such a scenario with censored demand and show that demand censoring leads to underordering and amplifies demand chasing behavior.

In another study involving another realistic demand scenario, Benzion et al. (2010) considers a setting where the demand distribution is unknown to the decision-maker. Although the authors show that there are differences between the subjects who know and don't know the demand distribution, knowing the demand distribution does not necessarily translate to improved newsvendor performance. Additionally, this study suggests that waste-aversion might be an important factor affecting order decisions.

3.9 Framing Effect

Framing or, the context how the problem is introduced to the decision-maker is an important factor affecting the decisions. Kremer (2008) compares the decisions made in newsvendor context and neutral context and shows that the context has crucial impact on the decisions as the decision errors in the neutral context are smaller. Schultz et al. (2018) also consider the framing effect and they manipulate the emphasis on the costs and the profits of the problem. However, the manipulation yields no significant difference.

3.10 Process Tracing

Process tracing is a method of observing the cognitive processes of individuals that take place during the making of a decision. These cognitive processes are captured through verbal protocols or technical recordings of how the decision-maker seeks specific information. For instance, in a newsvendor setting, a process tracing study can be by first telling the subject that they are supposed to make an inventory decision without giving the parameters of the problem. Then the experimenter lets the subject ask for all the information they need to make the inventory decision. These questions along with the order they are asked will give information about how the mental processes of the decision-maker works in this problem. This process tracing can also be conducted by hiding the relevant and some irrelevant information behind some buttons on the user interface of the experiment software. As the subject clicks on the buttons to uncover the information behind each button, the thought process would be recorded. Some studies use more advanced technologies of eye movement trackers and record where the subject looks on the screen. This method is a valuable tool in understanding how individuals make their decisions. There are several process tracing studies conducted in newsvendor context. These are Gavirneni and Isen (2010) and Cui et al. (2013). Their research revealed important information regarding the cognitive pathways used in newsvendor decision-making. Niranjana et al. (2023) use eye tracking to understand newsvendor decision making process.

3.11 Performance Measures

When analyzing decision-making in newsvendor scenarios, researchers typically focus on comparing the quantity ordered to the ideal amount. Yet, some studies choose to use different metrics, such as the likelihood of making the most optimal decisions or the percentage of maximum profit attained. In their influential work, Brown and Tang (2006) demonstrate that by using a specific profit target as a performance measure, it is possible to better understand instances of less-than-optimal ordering behavior.

4. Conclusion

The newsvendor model is a very commonly used model that is utilized not only in inventory management but also in many other areas. Data from the field and from laboratories show that humans do not make the optimal decision under newsvendor setting. This is true even when the subjects have formal training in newsvendor model. This suboptimal behavior leads to significant stock-outs and wasted inventory which result in severe profit losses. Thus, it is important to understand what affects the newsvendor decisions in order to remedy the situation. In this chapter, we briefly review the newsvendor experimental studies that have been conducted since 2000.

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