Behavioural Implications of Demand Perception in Inventory Management

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Abstract

The newsvendor problem is one of the rudimentary problems of inventory management with significant practical consequences, thus receiving considerable attention in the behavioural operational research literature. In this chapter, we focus on how decision makers perceive demand uncertainty in the newsvendor setting and discuss how such perception patterns influence commonly observed phenomena in order decisions, such as the pull-to-center effect. Drawing from behavioural biases such as overprecision, we propose that decision makers tend to perceive demand to be *smaller* than it actually is in high margin contexts, and this effect becomes more pronounced with increases in demand size. The opposite pattern is observed in low margin settings; decision makers perceive demand to be *larger* than the true demand, and this tendency is stronger at lower mean demand levels. Concurrently, decision makers tend to perceive demand to be *less variable* than it actually is, and this tendency propagates as the variability of demand increases in low margin contexts and decreases in high margin contexts. These perceptions, in turn, lead to more skewed decisions at both ends of the demand spectrum. We discuss how decision makers can be made aware of these biases and how decision processes can be re-designed to convert these unconscious competencies into capabilities to improve decision making.

1. Introduction

The newsvendor setting, as one of the fundamental models for inventory management, has been studied extensively in the operational research literature (see e.g., Porteus 2002 for a review) and has a variety of practical applications carrying significant consequences. The recent crises of Kentucky Fried Chicken (KFC) in 2017 is a felicitous example where inventory management problems led the company to the closure of hundreds of its restaurants in UK due to failed supply of its main ingredient - the chicken (O'Marah 2018, Owens 2018). In another example, Raz and Porteus (2006) report that the US publisher of Harry Potter and the Half Blood Prince had to rush to print 2.7 million additional copies when the book became the fastest selling in history. Similarly, Schweitzer and Cachon (2000) discuss how annoyed parents had to cope with disappointed children when Burger King restaurants underestimated the demand for free Toy Story movie toys to be included with their kids meal deals in 1996. Given its widespread practical as well as theoretical significance, the newsvendor problem thus emerged as a nascent topic of study in the behavioral operational research literature.

Since the seminal paper of Schweitzer and Cachon (2000) examining order decisions in controlled laboratory settings, experimental work on the newsvendor problem has consistently yielded the same insight: actual decisions are biased. Decision makers fail to order the normative (i.e., expected profit- maximizing) values and their decision behavior follows a particular pattern. This so-called *pull-to-center* pattern refers to the tendency of decision makers to set order levels between the normative quantity and average demand (see e.g., Bolton and Katok 2008, Bostian et al. 2008, Zhang and Siemsen 2016). For high profit products, such as books, bicycles and fashion apparel, this behavioral pattern implies orders lower than the expected profit-maximizing quantity, but higher than the average demand, while for products with low profit margins, such as computers, it leads to order values that are higher than the theoretical best, but lower than the mean demand (Schweitzer and Cachon 2000).

The pull-to-center effect has been shown to be robust when the basic newsvendor setting is extended to consider the impact of various factors, such as different feedback frequencies (Lurie and Swaminathan 2009), types of information (Gavirneni and Xia 2009), decision making in groups (Gavirneni and Isen 2010), gender differences (de Véricourt et al. 2013), and the framing of objectives (Schultz et al. 2018). Schweitzer and Cachon (2000) and Bolton and Katok (2008) argue that the pull-to-center effect can be explained by two special cases of the anchoring-and-adjustment heuristic (Kahneman et al. 1982): the tendency of decision makers to anchor on mean demand and adjust insufficiently toward the expected profit maximizing order quantities (*mean anchoring heuristic*), and the adjustment of current order quantities in line with previous period's demand realizations (*demand chasing*). Su (2008) proposes random optimization errors as the driver of the pull-to-center effect; however, Kremer et al. (2010) show that random errors do not fully explain this pattern, and the decision bias is context dependent. Other explanations for the pull-to-center effect proposed in the literature include overconfidence (Ren and Croson 2013), psychological costs of underage and overage (Ho et al. 2010), impulse balance equilibria (Ockenfels and Selten 2014), loss aversion and mental accounting (Becker-Peth et al. 2013), and prospect theory (Long and Nasiry 2014).

In this chapter, we focus on the decision makers' perceptions of demand uncertainty in the newsvendor setting as a possible driver of the pull-to-center effect. In particular, we propose that decision makers deviate from normative theory not necessarily because they lack the competency to set expected profit-maximizing order levels but because their perceptions of uncertain demand may be different from its true form; in essence, they order the "right" amount for the "wrong" demand. In the following, we first compare the perceived and actual properties of demand (i.e., demand size and variability) and investigate how they impact order decisions. We then examine whether the biases in the perception of uncertainty are context dependent; in particular, whether the difference between the perceived and true demand increases or decreases

as the properties of the underlying distribution change. In the final section, we discuss how decision processes can be redesigned to convert these unconscious competencies into capabilities to improve decision making.

2. Perception of Uncertainty in the Newsvendor Setting

In the traditional newsvendor setting, the decision maker determines, given the selling price and ordering cost, how many units to order of a product whose demand is uncertain. In the behavioral operational research literature, while investigating the possible drivers of the pull-to-center effect, Ren and Croson (2013) focus on the *variability* of the uncertain demand, and suggest that decision makers are *overprecise*, which they define, in the newsvendor setting, as "a biased belief that the distribution of demand has variance lower than its true variance" (p2504). Consequently, they model the overprecise perception of the actual demand distribution D as a mean-preserving, but variance-reducing transformation of the actual demand:

$$D_P = \beta D + (1 - \beta)E[D],$$

where the parameter $(1 - \beta)$ captures the decision maker's level of overprecision, and $E[D]$ is the mean of the actual demand D. Newsvendors with $(1 - \beta) = 0$ are perfectly unbiased (i.e., the true and perceived demand are the same), whereas $(1 - \beta) > 0$ indicates a belief that demand is less variable than it actually is. Ren and Croson (2013) propose that, overprecise newsvendors maximize expected profits, given the perceived demand, D_P; that is, their objective can be denoted by $max_x pE[\min(x, D_P)] - cx$, instead of the normative newsvendor objective function $max_x pE[\min(x, D)] - cx$, where p is the selling price, c is the cost of ordering, and x is the order quantity. It is argued that this behavior leads to the pull-to-center pattern; decision makers order less than the normative level in high profit margin situations, and order more than the normative level in low profit margin settings (see their Proposition 1 for a formal proof).

While Ren and Croson (2013) discuss the difference between perceived and actual demand variability, we argue that a biased perception of demand size may also result in suboptimal decisions. In order to capture this behavior, we model the decision makers' perception of the actual demand D as a variance-preserving, but mean-shifting transformation (i.e., a shift in demand in the sense of first order stochastic dominance; see Shaked and Shanthikumar 2007):

$$D_P = D + \delta,$$

where δ captures the direction and strength of the bias in the perception of demand size. If $\delta > 0$, then the decision maker perceives demand to be larger than it actually is, whereas if $\delta < 0$, then the perceived demand size is smaller than the true demand; newsvendors with $\delta = 0$ are unbiased. Like Ren and Croson (2013), we propose that, although decision makers may have the competency to set expected profit maximizing order levels, decisions are biased because the perceived and true demand sizes differ.

Schweitzer and Cachon (2000), among other possible utility functions and heuristics that might influence newsvendor decision making, consider aversion to overage **(**i.e., ordering more than the actual demand, and consequently, being left with unsold units**)** or underage (i.e., ordering fewer units than the actual demand, and consequently, having to turn away customers), and propose that decision makers who are averse to being left with unsold units would order less than the expected profit maximizing quantity, whereas those averse to having to turn away customers would choose quantities higher than the normative levels. This tendency could be equally attributed to the perception of demand size being different than the true demand. In particular, decision makers who perceive the demand size to be smaller would consequently believe the probability of overage to be higher than it actually is, and order less than the profit maximizing quantity; whereas decision makers who perceive demand to be larger than the true

demand, would also believe the probability of underage to be higher, and set order quantities higher than the theoretical benchmarks.

3. Impact of Changes in Demand Characteristics

We argued above although decision makers may have the competency to set normative order levels, differences in perceived versus actual properties of the demand distribution may impact their orders, hence leading to potentially biased decisions. This section examines how the observed patterns in demand perception behave when there is a change in the actual size or variability of the distribution.

Establishing that biases in demand perception are context dependent would prove beneficial for designing processes that use this unconscious competency to improve decision making. Furthermore, changes in demand are frequently encountered in practice; for example, airlines use advertising campaigns and promotions to increase demand for all fare classes (Cooper and Gupta 2006), or manufacturers face irregular orders from industrial customers responding to their own up and down demand (Davis 1993). Finally, such an analysis might provide insights about whether the deviations in perception of demand can always be equated with normative inaccuracy in the newsvendor context.

Changes in Demand Variability. To discuss how the perception of demand variability behaves as true variability changes, we refer to the data from Kocabıyıkoğlu et al. (2015). Although studying changes in demand was not the main focus of their study, their experimental design required participants to make newsvendor decisions under four different demand distributions with the same mean ($E[D] = 40$), but different variances (see Table 1 for the specific demand distributions used, and the corresponding variances). They manipulated change in demand via a within-subject design, and the participants worked with each demand distribution for 10 rounds. They considered both high profit margin ($p = 120, c = 30$) and low profit margin ($p =$

120, $c = 90$) settings; which was controlled with a between-subject design. 26 participants were assigned to the high profit margin condition, while there were 29 participants in the low profit margin condition. The average actual order decisions observed in Kocabıyıkoğlu et al. (2015), as well as the expected profit maximizing quantities, denoted by x and x^* respectively, are provided in Table 2.

Table 1. Demand distributions in Kocabıyıkoğlu et al.'s (2015) study

Distribution	Mean	Variance
Uniform(30,50)	40	33.33
Uniform(20,60)	40	133.33
Uniform(10,70)	40	300
Uniform(0,80)	40	533.33

Consistent with the rest of the behavioral operational research literature, the pull-to-center effect was observed in Kocabıyıkoğlu et al.'s (2015) experiments; the observed orders were greater than the corresponding normative quantities under the low margin scenario, and smaller than the theoretical benchmarks under the high margin scenario.

By using the data from Kocabıyıkoğlu et al.'s (2015) study, current work examined the existence of overprecision by calculating the overprecision parameters, $(1 - \beta)$. Through this analysis (see Figure 1), we observed that the overprecision parameters were uniformly positive, indicating their participants perceived demand to be less variable than it actually is. This is in line with Ren and Croson's (2013) results, which suggest overprecision as one of the drivers of the pull-to-center pattern.

Table 2. Actual and expected profit maximizing orders in Kocabıyıkoğlu et al. (2015)

	high margin setting		low margin setting	
	x	x^*	x	x^*
Uniform(30,50)	39.4	45	38.11	35
Uniform(20,60)	40.13	50	35.85	30
Uniform(10,70)	40.94	55	35.83	25
Uniform(0,80)	41.41	60	33.42	20

The parameters provided in Figure 1 suggest the decision makers' degree of overprecision did not stay constant across demand sizes. Rather, the higher overprecision parameters observed at lower variability levels when the profit margin was high suggest that the decision makers' tendency to perceive a more stable demand (i.e., perceive demand to be less variable than it actually is) became weaker when demand was more variable. The opposite pattern emerged in the low margin scenario. That is, overprecision parameters were lower at lower variability levels (for example, $(1-\beta) = 0.62$ when demand was distributed *Uniform*(30,50) and $Var(D) = 33.33$, while $(1-\beta) = 0.72$ under demand distribution *Uniform*(10,70), with corresponding variance $Var(D) = 300$) implying that the decision makers' perception that demand is more stable (i.e., less variable than it is in reality) became stronger when demand was more variable.

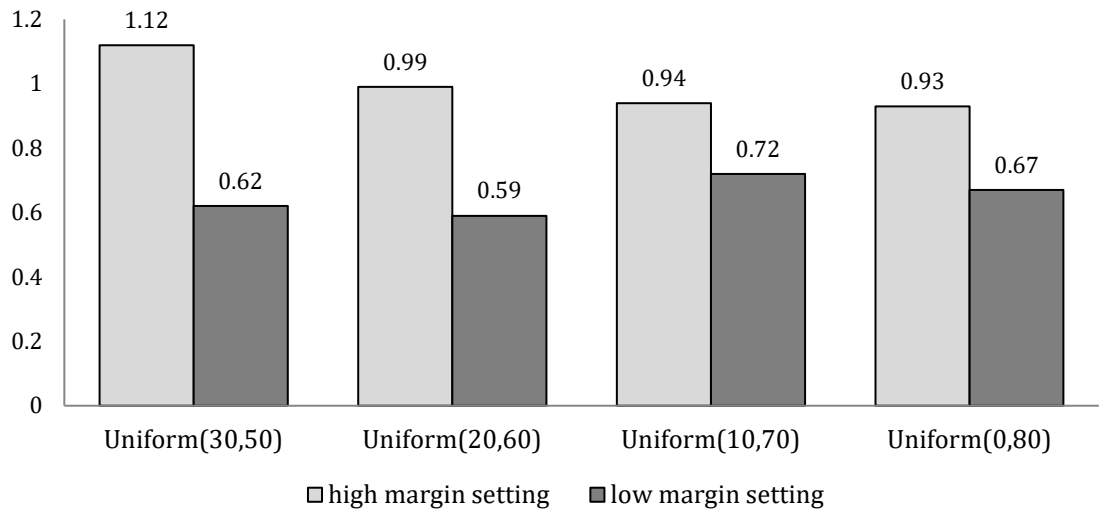

Figure 1. Overprecision parameters $(1-\beta)$

The results discussed above suggest that the strength of decision makers' tendency to perceive demand to be less variable than in reality is context dependent. Such an "induced stability bias" may have significant ramifications for demand forecasts and order decisions and needs to be taken into account when designing systems/procedures to support and enhance decision making. Furthermore, decision makers' perception of demand vis-à-vis changes in variability emerge as a pattern that should be given particular importance in both *high risk markets* that yield low margins, as well as in *low risk markets* that yield high margins, since the difference between the true and perceived demand propagates widely in such settings.

Changes in Demand Size. In other ongoing work, Kocabıyıkoğlu et al. (2018) investigate the impact of demand size on newsvendor decisions with a controlled laboratory study. In particular, they present an experiment which consists of 40 rounds, where every 10 rounds, the demand distribution changed in a manner that shifted the mean while preserving the variance (see Table 3 for the specific demand distributions used with corresponding mean values). The selling price was set as $p = 120$; 47 participants worked with $c = 30$ (i.e., the high margin setting), while 46 participants were told the ordering cost was $c = 90$ (i.e., the low margin

setting). Table 4 provides the average actual orders observed, x, and normative quantities, x^*, under both profit margin scenarios.

Table 3. Demand distributions in Kocabıyıkoğlu et al.'s (2018) study

Distribution	Mean	Variance
Uniform(0,80)	40	533.33
Uniform(10,90)	50	533.33
Uniform(20,100)	60	533.33
Uniform(30,110)	70	533.33

Before we discuss how the perception of demand size behaves with respect to variance-preserving but mean-shifting changes in the distribution, we note from Table 4 that the participants in this latter study exhibited the pull-to-center pattern. In particular, they ordered more units than the expected profit maximizing quantity in the low margin setting (suggesting they perceived demand to be larger than it actually is), and fewer units than the normative level in the high margin setting (suggesting they perceived demand to be smaller than its true form). To measure the strength of this bias and how it behaves with respect to changes in demand size, we calculate the demand size parameters δ for order decisions and Figure 2 presents this analysis.

Figure 2 presents consistently negative δ values in the high margin setting, and positive δ values in the low margin setting, confirming that participants perceived demand to be smaller than it actually is when the profit margin was high, with the opposite tendency influencing decisions in the low margin setting. Furthermore, this difference between the perceived and true demand sizes was not constant across demand distributions. In particular, in the low margin setting, the tendency to perceive demand to be larger than it actually is weakened at higher mean demand levels. For example, the demand size parameter δ was 25.04 when demand was

distributed *Uniform*(0,80) and $E[D] = 40$, while it was 13.73 when demand was distributed *Uniform*(30,110) and $E[D] = 70$. In the high margin setting, the strength of the tendency to perceive demand to be smaller than it actually is also varied across demand sizes; specifically, it became stronger at higher mean demand levels. For example, the demand size parameter was $\delta = -9.61$ when demand was distributed *Uniform*(0,80) and $E[D] = 40$, while it was -19.92 under *Uniform*(30,110), with $E[D] = 70$.

Table 4. Actual and expected profit maximizing orders in Kocabıyıkoğlu et al. (2018)

	high margin setting		low margin setting	
	x	x^*	x	x^*
Uniform(0,80)	50.39	60	45.04	20
Uniform(10,90)	52.17	70	47.08	30
Uniform(20,100)	58.24	80	55.13	40
Uniform(30,110)	70.08	90	63.73	50

The analysis above on the context-dependency of this "induced scale bias" is in line with the findings on demand variability discussed previously. Although the "misperception" of demand size gets weaker as the market grows for low profit margin products, in high profit margin industries, this bias gets stronger, and would potentially impede building market share by leading to consistent under-ordering, and consequently, higher numbers of turned-away customers.

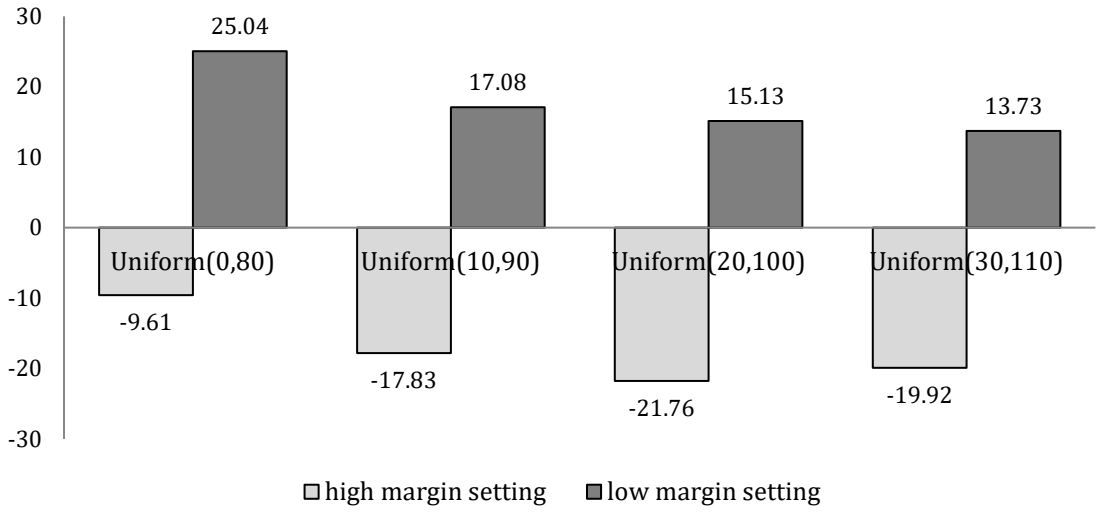

Figure 2. Demand size parameters δ

4. Aligning the Perceived and True Demand

This chapter posits that perceptions of demand uncertainty can potentially influence and bias newsvendor decision making. We argue, although decision makers may have the competency to set order quantities in line with normative benchmarks, they may not fully exploit this capability due to potential biases in perceptions of demand size and variability. Next, we discuss possible interventions in this context that may help to improve newsvendor decisions.

One of the main aims of behavioral operational research studies is understanding human behavior and decision processes, and their impact on system consequences to build tools for re-designing, managing and improving them. Two intervention approaches have consequently been identified in the behavioral literature (Gino and Pisano 2008): (i) a prescriptive approach, which suggests integrating these unconscious effects into the formal models, and (ii) a descriptive approach, which highlights the relevance of being aware of and understanding individual decision processes and their shortcomings. The prescriptive approach can be used

when a decision maker's biases may be corrected via feedback and training, while the descriptive approach provides guidance in cases where de-biasing is not feasible.

Unlike other factors that have been identified in the literature as affecting inventory management decisions, like the frequency of feedback (Lurie and Swaminathan 2009) or making decisions in groups (Gavirneni and Isen 2010), the uncertainty the organization is facing cannot be re-designed under most circumstances, except for indirect interventions through, for example, pricing and advertising (see e.g., Petruzzi and Dada 1999), and remains primarily exogenous. Although this may suggest that descriptive interventions are more appropriate, prescriptive solutions might also be adopted, since the organization can design interventions to counteract the shortcomings in demand perceptions via internal procedures; that is, it may be possible to aid/enable the decision maker to set the "right" order quantity, for the "right" demand.

A possible intervention may take the form of re-designing the decision task to incorporate, for example, nudges to reduce overprecision. In the literature, Lichtenstein and Fischhoff (1980), Arkes et al. (1987) and Koriat et al. (1980) have proposed such methods, and Ren and Croson (2013) have successfully applied the SPIES tool (Haran et al. 2010), which is based on eliciting likelihoods over the entire range of possibilities rather than asking for the 90% confidence interval, to reduce overprecision and improve newsvendor decision making. Similarly, Plous (1995) found that group judgments are less overprecise than individual judgments, which suggests delegating inventory decisions to teams might reduce the bias in demand perception and improve decision making.

Another possible intervention mechanism might be providing structured feedback and decision support for inventory managers to bring their demand perceptions closer to reality. Analytics tools and simulations to help the decision makers' conceptualization of the parameters and shape of the demand distribution may be effectively employed. Along similar

lines, comparisons with other managers' perceptions, combined benchmarks and/or past demand realizations could prove informative. It is worth noting that such support systems need to be monitored and frequently updated; otherwise, the bias in inventory decisions might be magnified leading to spillover effects. If decision makers are not promptly made aware of the changes in demand, they would still be setting orders for the now obsolete distribution, which is already perceived differently from its true form. For example, if the decision makers' strategies lag behind the market growth in a high margin industry such as fashion retail, this would lead to further under-ordering, due to inventory managers both not taking into account the actual increase in the market size, as well as perceiving demand to be smaller than it actually is.

Organizations can also influence their inventory managers' demand perceptions by providing incentives designed to align the perceived and true demand. Since incentive plans are based on various performance measures (e.g., Sarin and Winkler 1980), such a scheme could focus on order decisions and/or profits, which can be monitored by the organization, and aim to influence the decision makers' perception of demand through bringing these measures closer to their normative levels, and discouraging under- and over-ordering.

Evidence discussed so far indicates that ordering fewer units than the theoretical best is more prevalent for products with high profit margins. One way to prevent this might be introducing penalties for lost sales; however, two potential issues might render this type of scheme impractical. Firstly, although there is evidence that imposing negative incentives may lead to better performance (Goldsmith and Dhar 2013), a strong conviction that people will not respond to such plans exists[1], and they can potentially make managers' earnings unstable and

[1] https://spinify.com/blog/positive-effect-negative-incentives/

hard to predict (Basu et al. 1985). Furthermore, because of the imperfect observability of demand (Dai and Jerath 2013, Besbes and Muharremoglu 2013), monitoring lost sales may not be feasible; "newsvendors observe sales realizations, rather than demand realizations" (Rudi and Drake 2014, p.1335). Introducing incentive plans with sales-dependent components (see e.g., Basu et al. 1985, Lal and Staelin 1986), such as piece-wise linear commissions per unit sale might potentially motivate inventory managers to increase order levels and avoid under-ordering. We note that, careful monitoring of such a system is essential, to prevent decision makers from driving up order quantities beyond the normative levels in response to such a reward structure (Kalra et al. 2003).

In low profit margin settings, on the other hand, decision makers are observed to order more units than optimal. Although measuring performance in terms of unsold units might be easier practically, imposing a penalty for overage might still prove to be complicated, because of the factors discussed above. Rewarding managers for selling fewer units would be equally impractical and counterintuitive. A quota-based system (Raju and Srinivasan 1996, Mantrala et al. 1994, Chen 2000), that sets thresholds for unsold units, and rewards decision makers as experienced unsold units falls below certain levels might be used to prevent over-ordering. The constant re-evaluation of such an incentive system, for example, tracking managers who consistently experience no unsold units, is imperative as it might motivate decision makers to drop inventory levels sharply, particularly when lost sales are difficult to monitor. It should be noted, however, that the update frequency of the system should be carefully determined, since although shorter evaluation windows increase the motivating power of the plan, they also add to administrative expenses (Churchill et al. 1993).

5. Conclusions

Studies of newsvendor decision making in controlled laboratory environments have established that actual order decisions deviate from theoretical benchmarks and proposed possible drivers

for this pattern (see e.g., Schweitzer and Cachon 2000, Bolton and Katok 2008). In this chapter, we propose that the order decisions may be biased primarily due to distorted perceptions of demand uncertainty. We compare actual and perceived demand in terms of size and variability, and investigate how this gap behaves with respect to changes in the properties of demand. Table 5 provides a summary of this chapter's insights. We also discuss intervention mechanisms (summarized in Figure 3), which can be used individually or collectively, including decision support systems and incentive schemes, that acknowledge the decision makers' unconscious competencies, and propose re-designing tasks to manage and improve decision making processes. While the focus was on the newsvendor domain, we believe that our findings on distorted perceptions of uncertainty may resonate across a multitude of behavioral operational research platforms.

Table 5. Summary of results

	PERCEPTION OF	
	DEMAND SIZE	DEMAND VARIABILITY
HIGH MARGIN SETTING	• smaller than true demand • gets stronger at higher mean demand levels	• less variable than true demand • gets stronger at lower variability levels
LOW MARGIN SETTING	• larger than true demand • gets stronger at lower mean demand levels	• less variable than true demand • gets stronger at higher variability levels

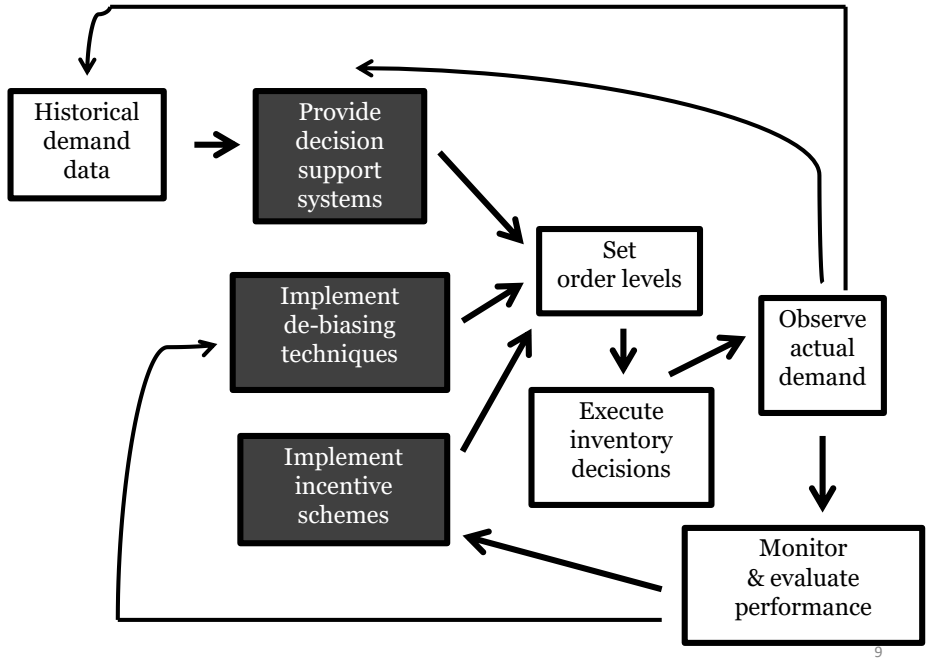

Figure 3. Intervention mechanisms to align true and perceived demand

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