



Invited research paper

Individual differences in the newsvendor problem: Behavior and cognitive reflection

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ABSTRACT

Previous research has shown that when solving a newsvendor problem, individuals systematically and persistently deviate from the profit maximizing quantity. This paper investigates the relationship between cognitive reflection and newsvendor decision making, testing experienced supply chain professionals and subjects affiliated with a university business school in a newsvendor experiment. We find that in high and medium critical ratio environments, individuals with higher cognitive reflection exhibit a lower tendency to chase demand. We also find that cognitive reflection is related to task outcome measures including average expected profit, average order quantity and order quantity variance, and that cognitive reflection is a better predictor of performance than college major, years of experience, and managerial position. These results suggest that cognitive reflection contributes to an understanding of newsvendor decision-making behavior.

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1. Introduction

Our understanding of how people make inventory decisions has advanced significantly in the past decade. The seminal work of Schweitzer and Cachon (2000) revealed that when facing newsvendor decisions, the average response is to select an order quantity between the profit-maximizing optimal quantity and the mean demand. Subsequent work has tested different explanations for this average behavior (Kremer et al., 2010; Su, 2008) and examined how this behavior changes with experience and training (Bolton and Katok, 2008; Lurie and Swaminathan, 2009; Bolton et al., 2008). More recently, the research scope has expanded to examine the impact of environmental factors such as censored demand (Rudi and Drake, 2009) and group decision making (Gavirneni and Xia, 2009). Several studies have observed wide variation in ordering between individuals, but few studies have documented causal factors to explain this individual variation.

Much of the prior newsvendor research has reported average results, which implicitly assumes that decision makers are homogeneous. However, research in many disciplines has pointed to the importance of measuring attributes of individual respondents and using this information to explain some of the variance in the results.

For example, research in cognitive psychology (Stanovich and West, 2000) and consumer behavior (Hutchinson et al., 2000) identified unobserved heterogeneity, also known as individual differences. In operations management, Doerr et al. (2004) highlighted worker heterogeneity and its impact on the variability of performance in assembly lines. Within inventory research, several studies point to the importance of individual differences in decision makers. Croson and Donohue (2006) called for theoretical research that incorporates individual biases. Similarly, Bendoly et al. (2006) highlighted the importance of finding out if humans act in accordance with how they are modeled, and specifically if differences are systematic and predictable. Cantor and Macdonald (2009) showed that individuals primed for abstract problem solving performed better than those primed for a concrete approach. Su (2008) developed a model that applies bounded rationality to newsvendor decisions, while calling for additional research and theory to look at cognitive limitations of individuals. In addition to a general observation about individual heterogeneity in judgment, Bolton and Katok (2008) specifically called for theory to explain individual variance in newsvendor-type decisions.

The goal of this paper is to apply theory from judgment and decision-making to explain some of the individual variation observed in a newsvendor task. We hypothesize that the individual-specific construct of cognitive reflection, as measured by the Cognitive Reflection Test (CRT) (Frederick, 2005), is related to chasing behavior and task outcome. We test this in three experimental studies across a range of critical ratio conditions using both experienced practitioners and students. In Study 1, we focus on the high critical ratio setting since this is the most representative scenario

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faced by our industry partners. Our subjects are from a pool of experienced supply chain managers/analysts from three Fortune 500 firms. Using experienced professionals also allows us to test the impact of individual characteristics that are often considered in hiring decisions, such as college major, years of professional service, and managerial position. In Study 2, we evaluate outcomes in high, medium and low critical ratio conditions in a controlled laboratory environment using subjects from a business school subject pool. In Study 3, we further test the low critical ratio setting using experienced professionals from a fourth firm.

We find that individuals with high cognitive reflection are less likely to chase demand in high and medium critical ratio settings, but observe no significant relationship between cognitive reflection and chasing behavior in low critical ratio settings. Similar results hold for task outcomes, including expected profit, average deviation from the optimal order quantity and order variance. The data also shows that cognitive reflection is a better predictor of task outcome than other individual characteristics such as college major, years of experience, or managerial position.

Section 2 begins with an introduction to the theory underlying this research. Section 3 develops the research hypotheses and the experiment. Sections 4–6 report the results, and Section 7 summarizes the findings and suggests opportunities for further research.

2. Theory development

In the newsvendor model, a decision maker is faced with the task of selecting an order quantity Q to satisfy stochastic demand D during a single sales period. The decision maker incurs a cost c for each unit purchased, earns price p for each unit sold, loses customer goodwill g for each unit of unsatisfied demand, and receives a unit salvage value s for each unit of unsold inventory. The cost of having one too few units relative to demand (underage) or one too many units relative to demand (overage) are then $c_u = p - c + g$ and $c_o = c - s$, respectively. For a given order quantity Q and demand realization D , the realized mismatch cost for the period is $G(D, Q) = c_o(Q - D)^+ + c_u(D - Q)^+$ and the realized profit is $\Pi(D, Q) = (p - c)D - G(D, Q)$. The normative solution to a newsvendor problem is to choose the order quantity that maximizes expected profit

$$\Pi(Q) = \int_{D=0}^{\infty} \Pi(D, Q) f(D) dD, \quad (1)$$

where $f(D)$ is the demand density function. The optimal order quantity for this objective is

$$Q^* = F^{-1} \left(\frac{c_u}{c_u + c_o} \right), \quad (2)$$

where $F^{-1}(\cdot)$ is the inverse of the cumulative distribution function for demand and $c_u/(c_u + c_o)$ is the critical ratio.

Although the newsvendor problem has a long history of published research (Edgeworth, 1888), deviations from the optimal order quantity are frequently observed in both experimental and industrial environments (e.g., Fisher et al., 1994). In repeated newsvendor contexts, persistent and well-documented deviations from the optimal order quantity include a tendency to over-order in a low critical ratio setting and under-order in a high critical ratio setting. Previous research suggests a number of possible explanations for this behavior. Even when the distribution of demand is known, average ordering behavior is somewhat consistent with heuristics such as anchoring on the mean, while prior evidence for consistent demand chasing is weak or non-significant (Schweitzer and Cachon, 2000). Bostian et al. (2008) observed that for some individuals, order quantity decisions are consistent with use of a

demand-chasing heuristic. Similarly, Kremer et al. (2010) reported that, in some cases, demand chasing is significant at the individual level. Feng et al. (2011) found significant differences between American and Chinese subjects in both anchoring on the mean and demand chasing. In a more complex multi-echelon setting, Bloomfield et al. (2007) found that order quantities selected by individuals were not sufficiently sensitive to relative costs. Bloomfield et al. (2007) also found that some of the same behavioral factors in the newsvendor problem also occur in situations where inventory is replenished over time, and that inventory errors are exacerbated with transit lags. Bolton and Katok (2008) found that performance improves when individuals are prevented from drawing conclusions from inappropriately small samples. However, they observed anecdotally that the tendency for “too-quick” conclusions based on small samples seemed to vary widely between individuals. Olivares et al. (2008) examined newsvendor decision making in a health-care setting and devised structural estimates of the mismatch cost ratios implied by observed inventory decisions. They found that individuals place greater weight on more tangible overage costs (e.g., idle operating room capacity) than on less tangible underage costs (e.g., staff overtime). While many papers describe potential heuristics and preferences that individuals might use to solve a newsvendor problem, little theory has emerged to explain or predict the observed heterogeneity between individuals.

2.1. Cognitive reflection and dual process theory

To better understand the decision-making process of individuals in the newsvendor problem, we draw from the fields of cognitive science and judgment and decision-making. While a number of possible heuristics have been proposed to explain newsvendor behavior, our research posits that cognitive reflection (Frederick, 2005) provides a theoretical foundation for understanding and explaining a portion of the individual heterogeneity observed in newsvendor decisions. Cognitive reflection refers to the tendency of an individual to let his or her System 2 process moderate, override, or endorse an initial System 1 response. Rooted in dual process theories of decision making (Stanovich and West, 2000), these two systems are parallel cognitive approaches activated when an individual solves a problem. System 1 processes are typically described as intuitive, tacit, contextualized and rapid while System 2 processes are reflective, analytical and rely on abstract reasoning. While there is a large body of literature detailing aspects of these two approaches, and not all scholars agree on terminology and all details of the two processes, (e.g., Evans, 1984, 2008; Hammond, 1996; Sloman, 1996; Stanovich and West, 2000; Kahneman and Frederick, 2002; Kahneman, 2011), the key concept is that these are different cognitive processes that are simultaneously active in decision making. The two systems work together, with System 1 generating suggestions for System 2 to consider in the forms of “impressions, intuitions, intentions and feelings” which, if endorsed by System 2, turn into beliefs and voluntary actions (Kahneman, 2011). Kahneman (2011) notes the degree of cognitive reflection may vary by individual, as well as with task environment and experience.

In some newsvendor decision contexts, intuitive, descriptive, and experiential decision inputs (typically governed by System 1) may have a role in generating the profit-maximizing order quantity. This occurs when limited relevant historical demand data is available to characterize future demand. For example, some individuals may have a particularly keen intuitive sense for predicting future demand for fashionable and trendsetting items. Similarly, while it is often difficult to estimate lost goodwill (g), some individuals may have skills or experience in making such an estimate. In such settings, System 1 may play a larger role in the decision process.

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