Operations Research Letters 45 (2017) 191–198

Contents lists available at ScienceDirect

Operations Research Letters

journal homepage: www.elsevier.com/locate/orl

Risk aversion and implicit shortage cost explain the Anchoring and Insufficient Adjustment bias in human newsvendors

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A R T I C L E I N F O

Article history:
Received 11 July 2016
Received in revised form
14 January 2017
Accepted 16 January 2017
Available online 23 January 2017

Keywords:
Human newsvendor
Risk aversion
Shortage cost
Behavioral operations

A B S T R A C T

The Anchoring and Insufficient Adjustment (AIA) bias has been observed in many newsvendor experiments, although a mathematical explanation for this behavior has previously eluded researchers. We show here that risk aversion coupled with an implicit shortage cost, both of which are well-known components of newsvendor decisions, comprehensively explains this behavior. We construct combinations of a risk-averse utility function and a shortage cost that explain the results from previously reported newsvendor experiments.

1. Introduction

Laboratory experiments using human newsvendors ([16] first, followed by [1–3,10,6,11]) observed that they ordered less (more) than the optimal quantity in the high (low) profit margin condition. [16] showed that this bias cannot be explained exclusively by risk aversion, risk seeking, loss aversion, waste aversion, stockout aversion, or underestimation of opportunity costs. They suggested that prospect theory might be able to account for this order pattern, but this was recently [12] shown to not be the case. [16] also suggested that ex-post inventory preference could explain this behavior, but acknowledged that it was not able to account for the observed asymmetry in the low margin and high margin settings. This observed asymmetry also cannot be explained by newsvendor overconfidence as manifested by underestimating the variability of demand, as analyzed by [14]. Finally, [16] mentioned in passing that a combination of these preferences, such as risk aversion and stockout aversion, might be able to explain this bias, but did not elaborate on how such a combination could be constructed. We show that risk aversion coupled with shortage cost (sometimes referred to as loss of goodwill, as in [11]) is the only pair of causes that can comprehensively and reasonably characterize the AIA bias. After analytically establishing this result, we fit the model to data from [16] and construct the specific forms of the risk aversion function and the shortage cost value that result in their findings.

2. The newsvendor decision

The basic parameters of a typical newsvendor decision are the demand distribution ($\xi \sim U[l, u]$), selling price (p), and purchase cost (c). While the demand can be from any probability distribution, for ease of analysis and consistency with most of the existing newsvendor experiments, we assume here that the demand follows a uniform distribution. We also consider demand to be continuously distributed, in contrast to much of the existing behavioral literature that assumes it to be discretely distributed. Our objective (under the assumption of risk-neutrality) is to determine the order quantity (Q) that maximizes the expected profit $\bar{\Pi}(Q) = E_\xi[\Pi(\xi|Q)]$, where $\Pi(\xi|Q)$ is the profit realized when demand is ξ and the order quantity is Q. That is,

$$\Pi(\xi|Q) = \begin{Bmatrix} p\xi - cQ & \text{if } \xi \le Q \\ (p-c)Q & \text{if } \xi \ge Q \end{Bmatrix}.$$

The optimal order quantity, Q^*, can be computed as $l + (u-l) \times \left(\frac{p-c}{p}\right)$. When c is greater than $\frac{1}{2}p$, the optimal order quantity is smaller than $\mu = \frac{1}{2}(l+u)$, the mean demand. On the other hand, when $c \le \frac{1}{2}p$, $Q^* \ge \mu$. [16] used the setup $l = 0$, $u = 300$, $p = 12$, $\bar{c} = 3$, and $\underline{c} = 9$, where $\bar{c}$ ($\underline{c}$) represents the purchase cost in the high (low) margin condition. We will consistently use $\bar{\ }$ to refer to the high margin condition and $\underline{\ }$ to refer to the low

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http://dx.doi.org/10.1016/j.orl.2017.01.005

Table 1
Effectiveness of the various pairs of the identified behavioral causes in explaining the observed quantities.

Waste aversion (t)	Stockout aversion (g)	Ex-post inventory error cost (δ)	Underestimated opportunity cost (β)	Overconfidence (γ)	Non-decreasing concave utility	Comments
14.163	15.698					Both t and g are unrealistically high ($>p$).
−1.535		15.698				$t < 0$; δ is unrealistically high ($>p$).
×			×			Impossible to achieve low-margin order quantity.
−1.535				25.0%		$t < 0$; γ is very low.
×					×	Impossible to achieve low-margin order quantity.
	1.535	14.163				g is reasonable; δ is unrealistically high ($>p$).
	×		×			Unable to match both observed order quantities.
	1.535			32.3%		g is reasonable; γ is very low.
	5.624				✓	g is reasonable; risk-aversion is reasonable.
		17.180	1.318			$\beta > 1$; δ is unrealistically high ($>p$).
		×		×		Unable to satisfy both first-order conditions.
		×			×	Unable to satisfy both first-order conditions.
			1.398	29.3%		$\beta > 1$; γ is very low.
			×		×	Impossible to achieve low-margin order quantity.
				×	×	Unable to satisfy both first-order conditions.

margin condition. The optimal order quantities in these two settings are $\underline{Q}^* = 75$ and $\bar{Q}^* = 225$. Define $\underline{Q}^o$ and $\bar{Q}^o$ to be the average order quantities chosen by the human subjects. Note that $\underline{Q}^o = 134 > 75 = \underline{Q}^*$ and $\bar{Q}^o = 177 < 225 = \bar{Q}^*$.

3. Proposed causes for the human bias

The following seven causes are commonly considered when explaining the AIA behavior in human newsvendor decisions.

1. Risk Aversion: Utility is a non-decreasing, concave function of profit, and the newsvendor's objective is to maximize expected utility. [5] showed that inclusion of risk aversion results in a lower order quantity for all settings of the problem parameters.
2. Waste Aversion (t): Any leftover inventory must be disposed of at an additional cost of $t(Q-\xi)^+$, implying that the salvage value is negative. This also universally reduces the newsvendor order quantities.
3. Stockout Aversion (g): Demand that cannot be satisfied from stock reduces the newsvendor profits by $g(\xi-Q)^+$, where g is the shortage cost that reflects the cost of lost customer goodwill. The presence of stockout aversion results in a uniformly higher order quantity.
4. Underestimated Opportunity Cost (β): The cost of underage, $c_u = p - c$, is discounted by a factor $\beta \le 1$. This results in a universal reduction in the order quantities.
5. Ex-post Inventory Error Cost (δ): The absolute difference between demand and order quantity incurs a cost $\delta|Q-\xi|$. This will move the optimal order quantities closer to the median. Note that, for [16], $\underline{Q}^o = 134$ will be achieved by $\delta = 22.125$, while $\bar{Q}^o = 177$ will be achieved by $\delta = 10.667$. Not only are these values inconsistent, they are also unrealistically high relative to $p = 12$.
6. Overconfidence (γ): [14] shows experimentally that overconfident newsvendors tend to demonstrate greater AIA by underestimating the variability in demand. Specifically, they postulate that the newsvendors were reacting to an affine mean-preserving transformation of the actual demand $\xi^o = \gamma\xi + (1-\gamma)\mu$, rather than the actual demand. Note that $\xi^o \sim U\left[\mu \pm \gamma\left(\frac{u-l}{2}\right)\right]$; *i.e.*, the newsvendor perceives the width (and standard deviation) of the distribution to be some fraction γ of its true value.
7. Prospect Theory: Developed by [9], prospect theory proposes that individuals are risk-averse over financial gains, but risk-seeking over financial losses. However, [12] showed that prospect theory is insufficient to explain AIA through an experiment where demand was shifted to [900, 1200], and AIA still existed, even though financial losses were not possible. We do not consider it further here.
8. Loss Aversion: This is a special case of risk aversion where the utility curve is piecewise-linear with a kink at 0. It also cannot explain the results of [12], and so is also not considered further.

Since no single bias can explain both the high-margin and low-margin observations from [16], we decided to evaluate all $\binom{6}{2} = 15$ possible pairs on their ability to explain the behavior. Three of these explanations (loss aversion, waste aversion, and underestimated opportunity cost) reduce the order quantity, so that combinations of these three cannot explain the higher order quantity in the low margin case. The results are detailed in Table 1, with each row representing a pair of the causes. For seven of the combinations there was no feasible set of parameters that could explain the [16] order quantities. For the pairs that did have a feasible solution, seven had parameters that we deemed to be unreasonable (e.g., parameters larger than the selling price p). Only one pair — stockout aversion and risk aversion — was able to reasonably explain the results of [16]; we explore this combination further in the remainder of this paper.

Of course, it is certainly possible that combinations of three or more causes could also explain this bias. Of the $2^6 - \left[\binom{6}{0} + \binom{6}{1} + \binom{6}{2}\right] = 42$ combinations of three or more causes, 15 will contain both risk aversion and stockout aversion, which are sufficient to explain the AIA bias by themselves. Some (for example, the combination of risk aversion, waste aversion, and underestimated opportunity cost) uniformly reduce the order quantities, and so are not able to explain the low-margin results. Others provide solutions that are not realistic. For example, consider the combination of stockout aversion (g), waste aversion (t), and ex-post inventory error cost (δ). With three causes and two observations ($\bar{Q}^o$ and $\underline{Q}^o$), the particular parameter values will no longer be uniquely defined. [16]'s observed values can be explained by any combination of these three parameters that satisfies the two linear equations

$$18\delta + 59t - 41g = 192$$
$$16\delta - 67t + 83g = 354.$$

However, it turns out that for this example there is no solution to these two equations for which all three parameters take on reasonable values (between 0 and p).

More generally, we have found that any reasonable combination of causes that explains AIA must include either risk aversion or shortage cost. In other words, there is no feasible solution that explains AIA for reasonable values of t and δ ($0 \le t, \delta \le p$) and β and γ ($0 \le \beta, \gamma \le 1$).