Inventory Order Decisions in a Single Echelon: The Effect of Backorders

Research Question

Inventory shortages occur when the amount of a given product in stock falls short of a customer's order. They are often an indicator of suboptimal supply chain performance (Lee and Lodree Jr., 2010) and are usually classified as lost sales, backorders, or partial backorders —a fraction of the shortage is lost and the remaining fraction is backlogged—. Backorders incur increased administrative costs, potential emergency transportation costs, and cost of delayed revenue, among others. Lost sales costs are sometimes even more expensive than backorders costs given the opportunity cost of lost revenue and the loss of customer goodwill or loyalty associated with the former (Lodree Jr., 2007). Hence, suppliers frequently offer economic incentives to customers to place a backorder rather than risk losing sales (DeCroix and Arreola-Risa, 1998).

How suppliers should make inventory order decisions when unmet demand is backlogged is hence a relevant issue for business success. Accordingly, it has been largely addressed from a normative point of view with models analyzing emergency replenishments to fill backorders (e.g., Gallego and Moon, 1993; Khouja, 1996; Lodree Jr. *et al.*, 2008), customers either placing backorders or leaving without making the purchase (e.g., Lee and Lodree Jr., 2010; Lodree Jr., 2007), and incentives to customers to place backorders (e.g., Cheung, 1998; DeCroix and Arreola-Risa, 1998), among others. However, to the best of my knowledge, no previous work has tested behaviorally any of the previous models. In addition, descriptions of suppliers' inventory order behavior when unmet demand is backlogged come from too complex serial supply chain systems (e.g., Croson and Donohue, 2006; Sterman, 1989; Wu and Katok, 2006) where behavioral patterns cannot be clearly ascribed to particular product and/or environmental characteristics or some other unspecified dynamics driven by individuals' interactions (Bloomfield and Kulp, 2013).

The question of whether suppliers actually realize the benefits of backorders compared to lost sales has thus been left arguably unanswered. Hence, this study aims at providing a more informed answer to such question.

Experimental Design

I run a Newsvendor experiment in a *2x2* between-subjects design with lost sales vs. backorders and low- vs. high-safety stock condition to assess the effect of an inventory system with backorders on inventory order behavior more accurately. Note that I further simplify Bloomfield and Kulp's (2013) experiment by assuming no inventory accumulation, providing thus a clean test for the effect of backorders on inventory order behavior. Unlike them, I also include high- and low-safety stock levels since Newsvendor research suggests that behavioral effects may differ across safety stock levels (e.g., Bolton and Katok, 2008; Chen *et al.*, 2013; Ho *et al.*, 2010; Schweitzer and Cachon, 2000).

I set unit shortage cost at $p = 4$ and manipulate unit purchase cost c, setting it at $c = 1$ for high-safety stock items and $c = 3$ for low-safety stock ones. I consider an approximately normally distributed customer demand with mean $\mu = 50$ units and standard deviation $\sigma = 20$ units.[1] The chosen μ and σ values assure that the coefficient of variation is large enough to make an impact and small enough for a normal distribution to be reasonable (Rudi and Drake, 2014). All individuals experienced realizations from the same set of demand values, controlling for the impact of demand realizations on inventory order decisions.

For the Newsvendor problem (Arrow *et al.*, 1951), the described parameterization implies optimal inventory order quantities of 64 units ($q^*_{L,H} = 64$) in a high-safety stock condition and 37 units ($q^*_{L,L} = 37$) in a low-safety stock condition. For the Newsvendor problem extension to the case of backorders (Bulinskaya, 1964), the described parameterization implies optimal inventory order quantities of 67 units ($q^*_{B,H} = 67$) in a high-safety stock condition and 54 units ($q^*_{B,L} = 54$) in a low-safety stock condition. Note that $q^*_{B,L}$ is not strictly in the domain of a low-safety stock condition according to Switcher and Cachon's (2000) definition since it is larger than μ. However, it is referred as a low-safety stock condition for ease of exposition.

The experiment was programmed and run with the software z-Tree (Fischbacher, 2007). A total of 96 individuals participated in the experiment. Seven participants were removed from the data set since their inventory order behaviors suggest they were not particularly responding to shortages, resulting in unusual large backlogs during most of the game.[2] All participants were students attending a graduate Operations Management course in a Swiss university. The experiment was run as part of the course and monetary rewards were thus not used to incentivize participation.

Hypotheses

Figure 1 shows how increasing values of c affects optima in Arrow *et al.*'s lost sales setting and Bulinskaya's backorders one.

[1] Following Ho *et al.* (2010), I restrict the demand to positive integer values and use the term "approximately normal" instead of "truncated normal" to avoid confusing individuals.

[2] I repeated all analyses including all 96 participants. Hypothesis 1 downgrades to partially supported, whereas Hypothesis 3 remains partially supported. Hence, the reported results are fairly robust to outliers.

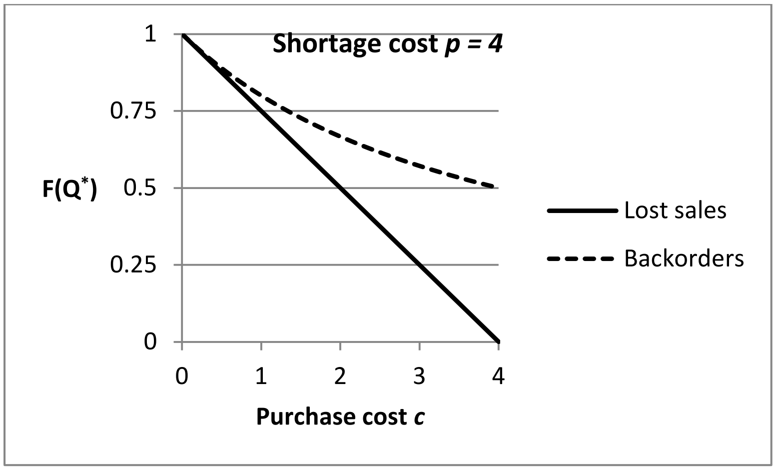

Figure 1. Optima behavior to increasing values of the purchase cost.

From a normative point of view, Figure 1 shows that backorders lead to larger optima than lost sales. It is thus arguably reasonable to expect an *inventory system effect* in the same safety stock condition, that is, *in the same safety stock condition, inventory order quantities in the backorders case will be larger than inventory order quantities in the lost sales case* (**Hypothesis 1**). Figure 1 also shows that differences in optima between both inventory systems differ across safety stock conditions. It is thus arguably reasonable to expect a *larger inventory system effect* in low- than in high-safety stock conditions, that is, *in the low-safety stock condition, differences in inventory order quantities between the backorders and lost sales cases will be larger than differences in inventory order quantities between the backorders and lost sales cases in the high-safety stock condition* (**Hypothesis 2**).

From a behavioral point of view, Ho *et al.*'s (2010) behavioral study of reference dependence in a multilocation Newsvendor problem offers some insights about the effects that backorders could have on inventory order behavior compared to lost sales. Ho and colleagues manipulated the relative salience of the disutilities of leftovers and shortages in low- and high-safety stock conditions, respectively, to reduce the pull-to-center effect and observed that both salient leftovers and shortages can induce smaller and larger inventory order quantities, respectively, and thus reduce the pull-to-center effect. In our case, backorders make shortages arguably more salient since they make shortages and their associated penalties to carry over to following periods until they are filled, making their detrimental effects to endure more in time. Thus, shortages should lead to larger order adjustments when they are backlogged than when they are lost. It is thus arguably reasonable to expect an *inventory system shortage effect* in the same safety stock condition, that is, *in the same safety stock condition, order adjustments after a shortage in the backorders case will be larger than order adjustments after a shortage in the lost sales case* (**Hypothesis 3**). In addition, loss aversion suggests that differences in order adjustments after a shortage between both inventory systems differ across safety stock conditions. In particular, large losses are presumably more important than small losses (Harinck *et al.*, 2007; Wilson and Gilbert, 2005) and consequently more likely to affect behavior (Smith *et al.*, 2009). In our case, the cost associated with backlog is larger in low- than in high-safety stock conditions due to the larger backlog filling cost in the former. Thus, shortages should lead to larger order adjustments for backorders than for lost sales in low- than in high-safety stock conditions. It is thus arguably reasonable to expect a *larger inventory system shortage effect* in low- than in high-safety stock conditions, that is, *in the low-safety stock condition, differences in order adjustments after a shortage between the backorders and lost sales cases will be larger than differences in order adjustments after a shortage between the backorders and lost sales cases in the high-safety stock condition* (**Hypothesis 4**).

Major Results

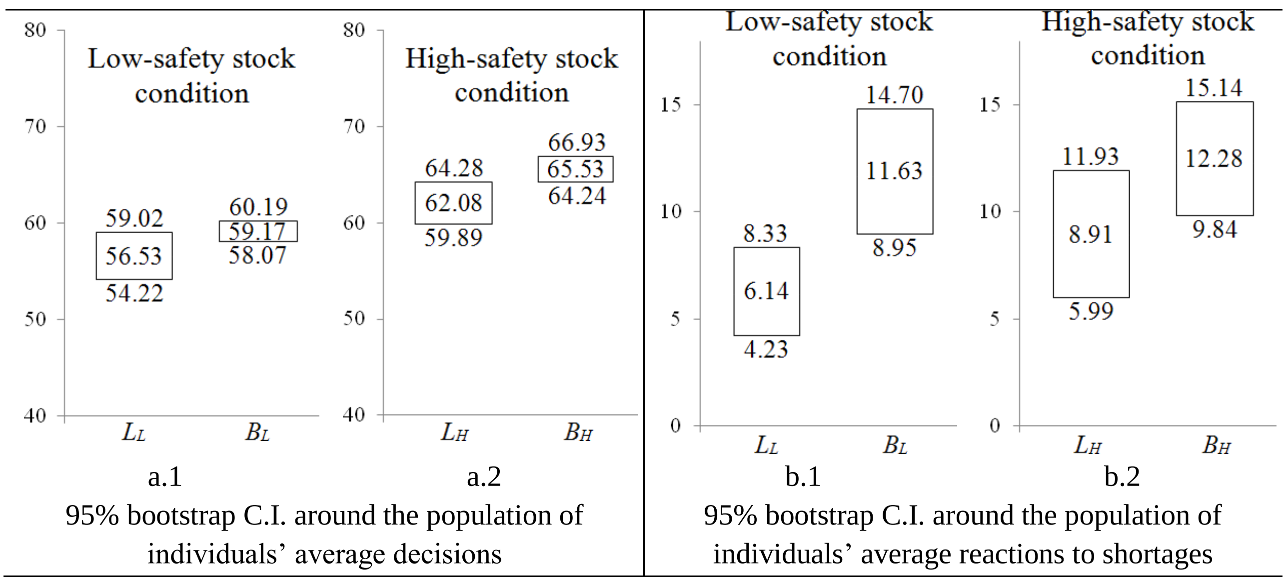

Figure 2. Overview of results.

The left panel in Figure 2 shows an overview of average decision behavior. It suggests that backorders lead to larger inventory order quantities than lost sales in the same safety stock condition. Wilcoxon Rank-Sum tests show there is a significant *inventory system effect* in the same safety stock condition (low-safety stock: $p\text{-}value_{1\ tail} = 0.0227$, high-safety stock: $p\text{-}value_{1\ tail} = 0.0068$), supporting **Hypothesis 1**. The panel also suggests that the *larger inventory system effect* in low- than in high-safety conditions does not hold directionally. An interaction effect between inventory system and safety stock condition ($p\text{-}value_{1\ tail} = 0.3350$), provides no support for **Hypothesis 2**.

The right panel in Figure 2 shows an overview of average adjustment behavior after a shortage. It suggests that shortages lead to larger order adjustments when they are backlogged than when they are lost. Wilcoxon Rank-Sum tests show there is a highly significant *inventory system shortage effect* in the low-safety stock condition (*p-value*$_{1\text{-}tail}$ = *0.0020*) and a marginally significant *inventory system shortage effect* in the high-safety stock condition (*p-value*$_{1\ tail}$ = *0.0571*), providing partial support for **Hypothesis 3**. The panel also suggests that the *larger inventory system shortage effect* in low- than in high-safety stock conditions holds directionally. However, the interaction effect between inventory system shortage and safety stock condition is not significant (*p-value*$_{1\ tail}$ = *0.2267*), providing no support for **Hypothesis 4**.

To further assess the impact of backorders, I compare distances to optima between both inventory systems in the same safety stock condition. Wilcoxon Rank-Sum tests show that participants are highly significantly closer to optimum in the backorders than in the lost sales case in the low-safety stock condition (*p-value*$_{1\ tail}$ = *0.0007*) and that one cannot rule out the possibility that distance to optimum in the backorders and lost sales cases is similar in the high-safety stock condition (*p-value*$_{1\ tail}$ = *0.3092*). Following a similar approach to Hypotheses 2 and 4, the effect is found to be significantly larger in low- than in high-safety stock conditions (*p-value*$_{1\ tail}$ = *0.0261*). That is, backorders bring orders closer to optimum more in low- than in high-safety stock settings.

From a normative perspective, backorders can be though as the opposite of lost sales regarding the way unmet demand is handled. However, from a behavioral perspective, they are related. In particular, and following the same line of reasoning of Ho *et al.* (2010), backorders do not eliminate the behavioral effect of lost sales but increase it or make them more salient in order to influence inventory order behavior in an intended direction. Normatively speaking, the Newsvendor optimum corresponds to small orders in low-safety stock settings; behaviorally speaking, individuals tend to place larger orders. I showed that backorders lead individuals to stronger reactions to shortages and larger orders, moving closer to optimum given this system's larger optimum. That is, there are benefits in both costs (or profits) and service expectations. Similarly, normatively speaking, the Newsvendor optimum corresponds to large orders in high-safety stock settings; behaviorally speaking, individuals tend to place smaller orders. I also showed that backorders lead to stronger reactions to shortages and larger orders. Notwithstanding there was no difference in distance to optimum, the observed behavior still represents higher product availability and hence higher customer satisfaction.

This study shows that suppliers may realize the benefits of a Newsvendor system with backorders compared to lost sales. Addressing some of its limitations promises to improve our understanding of its potential benefits. For instance, I assumed full backlogging and no incentives to customers to place backorders. In reality, suppliers may not be able to fill all the shortage and/or may offer customers incentives to place a backorder to avoid switching behavior. Hence, future work could explore the impact of these on suppliers's inventory order behavior. Likewise, I assumed no revenue metric. Hence, future work could explore how backorders affect inventory order behavior in a more traditional profit-based Newsvendor experiment.

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