IJACT 20-12-15

Sustainable Considerations for Newsvendor Decisions

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Abstract

It is important to have an appropriate amount of inventory for effective operations. This study seeks to develop a sustainable newsvendor model by incorporating environment-related costs into the existing well-known (single-period) newsvendor model. Since leftovers do more harm to environments than stockouts, the optimal order amount tends to be lower than the traditional quantity. However, this is not the case when a second buy is allowed. A second order opportunity is prevalent in industries where it improves demand forecast despite incurring extra costs. In this study, we conduct an extensive numerical analysis for a newsvendor situation with a permitted second buy. The results show that we can reduce inventory costs by considering sustainability concerns. The research idea of including sustainability considerations into existing inventory models can be extended to a more general case and provides managerial insights for better inventory decisions.

Keywords: Sustainability; Newsvendor model; Inventory decision; Second buy

1. INTRODUCTION

Inventory management is crucial to most companies for efficient and effective operations. Sufficient inventory is required to satisfy customer orders and not lose goodwill, particularly for manufacturing companies and their supply chains, whereas having too much inventory leads to a waste of resources. Apple Inc. once had a difficult experience providing iPhones in time to follow soaring demand, while some auto manufacturing companies had to close factory supply if too many automobiles remained on lots.

Maintaining an appropriate amount of inventory at all levels is one of the key factors that determines the successful operation of supply chains. In fact, inventory management has been a major area of study in the operations management field and many optimization models have been developed for inventory decisions. A newsvendor model [1], an economic order quantity model [2], and an order up to model [3] are some of the analytical models (with plenty of extensions) that have been widely studied.

In this study, we investigate how a newsvendor model would be adjusted to consider sustainability in inventory management. It is well known that organizations must take account of environmental and social responsibilities as well as their economic roles to continually exist within our society. This sustainability issue is receiving greater attention today as companies, without showing efforts to protect the environment or provide social welfare, cannot competitively survive in the long run.

The importance of sustainability in management has been revealed by a significant stream of research [4-7]. Particularly, there has been increasing interest in incorporating social and environmental aspects into inventory

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management in recent literature. This literature has focused on inventory-routing problems [8,9], life-cycle inventory [10-12], or gas emissions in inventory management [13-15]. This large amount of literature has dealt with various circumstances and with various methodologies to analyze how sustainability considerations affect inventory management, but it has not specified certain inventory models for optimization.

There have been approaches that adjust traditional inventory models to include sustainability concerns. Some articles have revisited a well-known economic order quantity (EOQ) model with an extended exergy accounting approach [16] by integrating environmental factors [17] or by including ergonomic principles [18]. There has not been, however, an approach to analyze a newsvendor model with sustainability considerations to our knowledge. This study is expected to be the first step to consider how optimal order quantities can be modified by incorporating sustainability-related inventory costs, principally under newsvendor settings.

When analyzing optimal inventory decisions with sustainability considerations over a single period, we realized optimal order quantities tend to decrease because large leftover inventories usually lead to costs such as waste disposal or storage. Whether the optimal newsvendor quantity should increase or decrease for sustainability reasons is not obvious if a second buy is allowed during a single selling season. The singleperiod inventory model with a second buy allowed is well-developed in the existing studies [19,20]. Unlike the scenario where only a single order is possible, a company can place a second order after incurring additional demand during the selling season. A second order is usually more expensive than the initial order but there is a benefit to using this opportunity because demand prediction accuracy can be enhanced once initial demand has been observed [21,22]. This scenario assumes that we can perfectly forecast total demand for the season [23].

In this study, we investigate how companies can achieve cost savings and what factors affect optimal ordering decisions and cost savings by incorporating sustainability-related costs into the traditional newsvendor model. The results of our numerical analysis show that inventory cost is reduced by considering sustainability when making inventory decisions. The sustainable newsvendor model proposed in this paper can be extended to a more general circumstance covering additional types of costs relevant to sustainability. In addition, the numerical results imply that we should emphasize sustainability to decide the optimal order quantity particularly when the premium paid for the second buy is relatively low.

The remainder of this paper is as follows. In section 2, we develop a sustainable newsvendor model, especially when there is the opportunity to place a second order for a single-period inventory problem. Section 3 reviews an extensive numerical analysis to observe the impact on newsvendor inventory decisions when considering sustainability. Finally, in section 4, we discuss and summarize the results and implications of this study and suggest directions for future research.

2. A SUSTAINABLE NEWSVENDOR MODEL

The traditional newsvendor model has been established since 1951 [24]. A single-period inventory problem can be solved by minimizing total cost which is the sum of the cost associated with leftover inventories and the cost associated with foregone profits. Specifically, the objective of the traditional newsvendor model is expressed as follows.

Minimize
$$C(Q) = c_o \int_0^Q (Q - x) f(x) dx + c_u \int_Q^\infty (x - Q) f(x) dx$$
 (1)
where Q is an order quantity for a single period,

where

 c_0 is the unit overage cost for leftover inventories,

 c_{μ} is the unit underage cost for foregone profits, and

f(x) is the probability distribution of demands.

The optimal order quantity satisfies the following equation.

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

where Q^* is the optimal order quantity for a single period, and F(.) is the cumulative probability distribution of demands.

In general, the unit overage cost is computed as the unit production (or purchase) cost and the unit underage cost is computed as the difference between the unit selling price and the unit production/purchase cost. When there are salvage values for some leftover inventories after a single selling season, the unit overage cost is expressed as the sum of the unit production/purchase cost and the unit salvage value.

For single-period inventory decisions, we agree that having fewer leftover inventories benefits the environment more because leftovers incur costs. For example, we may pay for waste disposal in an environmentally friendly manner. There is no additional cost for having less inventory than demand even when considering sustainability for a single-period inventory problem where only a single order before demand is realized is allowed. The optimal sustainable newsvendor quantity Q_s^* should therefore always be less than the optimal traditional order quantity Q^* (without considering sustainability) in this case.

In this paper we explore a single-period inventory problem when a second buy is allowed. When a company can place a second order after some of its demand is observed, the overage cost of the newsvendor model is the same as one with single-ordering. The underage cost becomes the unit premium, which is the marginal cost the company has to pay to purchase products the second time instead of buying the first time before demand occurs. This can be expressed as:

$$c_o = c$$

 $c_u = premium$

Let us consider sustainability issues for this case. From previous studies on sustainability and inventory management [7,17], we can identify the following three costs regarding environmental concerns.

- 1) Warehouse inventory holding cost (*h*)
- 2) Waste disposal cost (*wd*)
- 3) Transportation cost (trans)

Warehouse inventory holding cost occurs when the initial order quantity turns out to be greater than the demand during the selling period. When the second buy is allowed, there could be no leftovers to be stored in the warehouse. Thus, if the initial order is greater than demand, unnecessary warehouse cost will occur.

Waste disposal cost also occurs when there is greater inventory from the initial order quantity than demand. The company must pay for disposing of waste in a manner sufficient to protect the environment for inventories leftover at the end of a single selling season. If the demand is higher than the initial order quantity, there will be no leftovers as we assume we can satisfy the remaining demand by ordering the exact amount for the second buy.

Transportation cost, on the other hand, occurs when a second buy is implemented. When a company places orders twice instead of just once, additional transportation is required for the second shipment which generates gas emissions undesirable to the environment. We define this additional cost as the transportation cost that should be added to the underage cost of our sustainable newsvendor model.

To sum up, the optimal order quantity in this case is determined by

$$Q_{S}^{*} = F^{-1} \left(\frac{c_{u}}{c_{u} + c_{o}} \right)$$
where
$$c_{o} = c + h + wd$$

$$c_{u} = premium + trans$$
(3)

and the cost of ordering Q_S^* the first time is computed as

$$C(Q_{S}^{*}) = (c + h + wd) \int_{0}^{Q_{S}^{*}} (Q_{S}^{*} - x) f(x) dx + (preimum + trans) \int_{Q_{S}^{*}}^{\infty} (x - Q_{S}^{*}) f(x) dx.$$
(4)

It is not obvious whether the new optimal order quantity considering sustainability is higher or lower than the one without sustainability considerations. The relationship between cost parameters and the cost benefit of sustainability considerations is also not clear. In this respect, the numerical results in the following section provide an analysis.

3. NUMERICAL ANALYSIS

We have conducted an extensive numerical study to better understand the cost saving mechanism by incorporating sustainability-related costs into the traditional newsvendor model. We assume that a company decides an order quantity for a single selling season before demand occurs where the level of demand is uncertain, but its distribution is known. The company buys products at unit cost c and sells them at unit price p. At the end of the selling season, the company has to pay for the warehouse holding cost (h) and waste disposal cost (wd) if there are leftover inventories in addition to the already paid per unit purchase cost (c). After some of the demand is observed during the season, the company can place a second order to prevent stockout but the unit purchase cost is higher than that of the initial orders. We assume that the second order quantity is exactly the same as the amount by which the initial order is short of demand. As illustrated in the previous section, the optimal initial order quantity considering sustainability is computed as

$$Q_S^* = F^{-1} \left(\frac{c_u}{c_u + c_o} \right)$$
(5)
where $c_o = c + h + wd$

$$c_{u} = premium + trans$$

With the following setup of various parameters, we analyze 244 combinations by obtaining the optimal order quantities with and without sustainability considerations and compare their inventory costs. It is not possible to choose the parameters representing a real-world industry as there are too much variation throughout companies, but these combinations are sufficient enough to analyze the effect of parameter changes on the cost reduction for our study.

Demand distribution: Normal distribution with mean 100 Standard deviation of demands = $\{10, 20, 30\}$ h = 1 fixed as a ground measure $c = \{1, 3, 5\}$ $wd = \{1, 2, 3\}$ $premium = \{1, 3, 5\}$ $trans = \{1, 4, 7\}$

Table 1 summarizes the numerical observations with this setup. The above setup is determined to balance the critical ratios $(\frac{c_u}{c_u+c_o})$ for the two cases (with and without sustainability considerations). The inventory cost is calculated with all cost parameters including the sustainability-related costs (*h*, *wd*, *trans*).

Table 1. Numerical observations under our setup.				
	With sustainability considerations		Without considerations	sustainability
C.,	≥ 0.5	159 cases (65.43%)	≥ 0.5	162 cases (66.67%)
$\frac{c_u}{c_u+c_o}$	< 0.5	84 (34.57%)	< 0.5	81 cases (33.33%)
	average	0.5229	average	0.5
Average order quantity	101.151		100	
Average	97.29		106.34	
inventory cost	(SD: 50.48)		(SD: 56.82)	

The numerical results under our setup shows the inventory cost of Q_s^* is less than that of Q^* in all cases. The average cost of sustainable newsvendor quantities is 97.29 with a standard deviation 50.48 while the average cost of newsvendor quantities without sustainability considerations is 106.34 with a standard deviation 56.82.

The average Q_s^* is 101.151 and the average Q^* is 100 under our settings. This result is not quite intuitive. Unlike a single-ordering case, Q_s^* is not always less than Q^* , because of the transportation cost associated with the second order. Under our numerical setup, Q_s^* is greater than Q^* for 51.64% of total cases and Q_s^* is less than Q^* for 43.21% of total cases.

In order to analyze the cost savings of sustainability considerations, we define the following performance measure.

$$\text{Cost savings} = \frac{\mathcal{C}(Q^*) - \mathcal{C}(Q^*)}{\mathcal{C}(Q^*)}$$
(6)

This measure indicates how much inventory cost is saved if we decide an order quantity with sustainability considerations compared to a scenario where sustainability-related costs are not considered.



Figure 1. Effect of standard deviations of demands.



Figure 2. Effect of unit purchase cost c.

Figure 1 depicts average Q_s^* , average Q^* , and average cost savings with respect to the standard deviation of demand. Average cost savings were computed by averaging cost savings of the combinations by standard deviation of demand. Q_s^* increases when demand variability increases. Average cost savings are constant with the value 0.0744, implying that demand variability does not influence the benefits of using the sustainable newsvendor model. Under our specific settings, inventory cost is reduced by 7.44% on average.

Figure 2 shows the effect of unit purchase cost. As the unit purchase cost increases, both Q_s^* , and Q^* decrease as the underage cost increases. The magnitude of the decrease in optimal order quantity is lower for Q_s^* because its critical ratio $(\frac{c_u}{c_u+c_o})$ for inventory decisions has more cost parameters. Ordering Q_s^* instead of Q^* saves inventory cost, but the impact of unit purchase cost on cost savings is not clear.



Figure 3. Effect of unit waste disposal cost (wd).

Figure 3 illustrates the effect of waste disposal cost (*wd*). As the unit waste disposal cost increases, Q_S^* tends to decrease due to the increase of its overage cost and Q^* remains constant because its critical ratio does not change. Therefore, depending on the unit waste disposal cost, Q_S^* can be either higher or lower than Q^* .



Figure 4. Effect of unit marginal cost of the second order (premium).

Figure 4 shows the effect of the unit marginal cost of the second order (*premium*). As it increases, both the optimal order quantities with and without sustainability considerations tend to increase because their underage costs increase. The benefit of incorporating sustainability-related costs into the inventory decision is higher for relatively a lower premium imposed on a second order.



Figure 5. Effect of unit transportation cost (trans).

Figure 5 describes the effect of the unit transportation cost. As the unit transportation cost increases, Q_S^* tends to increase because it becomes more advantageous to not place a second order. Depending on the unit transportation cost, Q_S^* can be either higher or lower than Q^* . The impact of transportation costs on inventory cost savings is unclear.

4. DISCUSSION AND CONCLUSION

In this study, we have developed a sustainable newsvendor model which determines the environmentallyfriendly optimal order quantity for a single-period inventory problem when a second buy is allowed. If only a single order is possible during the selling season, environmental concerns will always force the optimal order quantity to be lower than that of a scenario without sustainability considerations because leftover inventories rather than stockouts incur greater environmental costs. Here, the second buy is more expensive than the initial order but it near perfectly meets the demand forecast. In this case, we can optimize initial order quantity by defining the overage cost as the sum of purchase cost, warehouse holding cost, and waste disposal cost and by defining the underage cost as the sum of marginal cost of the second order and additional transportation cost of the second order. Whether the optimal order quantity should increase or decrease to include sustainability concerns is not intuitive, unlike a single-ordering situation. As an observed result of the numerical analysis, it depends on cost parameters. In all cases the inventory cost can be reduced when accounting for sustainabilityrelated costs by ordering this optimal quantity instead of the traditional newsvendor quantity. The cost savings are relatively high especially when the marginal cost of the second order is low. In other words, incorporating environmental costs into a newsvendor decision is even more beneficial when the second order opportunity is less expensive.

There have been significant literatures about sustainable inventory management, but no article has yet attempted an optimal inventory decision for newsvendor conditions. This study provides a useful idea about how we can extend existing inventory models to contain sustainability concerns. With increasing importance in firms' environmental and social responsibilities, the optimization models for inventory decisions should be adjusted to include relevant costs. Although, in this paper, all the relevant costs might not be included as it is

not easy to quantify sustainability-related costs. Another limitation of this study is that the newsvendor quantity was computed using only unit cost parameters, but there may be a fixed cost that is not proportional to the order amount; this complicates the optimization problem.

Future research can search for the proper ways to quantify sustainability-related costs and to modify existing inventory models to reflect them. For a single selling season, the sustainable newsvendor model proposed in this paper can be extended to a more general circumstance covering different types of costs. Other inventory replenishment systems such as order-up-to, (s,S) policy, or (Q,r) policy can be also revised to integrate sustainability considerations. Research concepts will become more meaningful when they can be applied to sustainable inventory decisions throughout supply chains.

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