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Optimal inventory policy with supply uncertainty and demand cancellation

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ABSTRACT

We consider a periodic review model where the firm manages its inventory under supply uncertainty and demand cancellation. We show that because of supply uncertainty, the optimal inventory policy has the structure of re-order point type. That is, we order if the initial inventory falls below this re-order point, otherwise we do not order. This is in contrast to the work of Yuan and Cheung (2003) who prove the optimality of an order up to policy in the absence of supply uncertainty. We also investigate the impact of supply uncertainty and demand cancellation on the performance of the supply chain. Using our model, we are able to quantify the importance of reducing the variance of either the distribution of yield or the distribution of demand cancellation. The single, multiple periods and the infinite horizon models are studied.

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1. Introduction

This paper considers a single item, periodic review inventory model where demand is reserved and customers are allowed to cancel their orders, at the same time, the supplier is unreliable. Our objective is to derive optimal inventory policy for such a system. Due to relatively lower starting up costs, the internet has become an increasingly popular platform to gather more sales. As a result, more firms are employing web savvy operators to convert cyber-passerbys into sales via clicking. During a demand leadtime, there are many reasons why cancellation is tempting. Advertising campaign such as "money back guarantee" is very popular among online webshops to promote sales. Customers are usually given a limited amount of time to try a certain product and if they are not satisfied, a full refund can be given. Such risk-free promise on the part of the online retailer has motivated some customers to cancel their orders to try a different product. In the service industries among airline and hotel companies, the majority of bookings is reserved online. However, cancellation behaviour can be prevalent due to purchasing of travel insurance such as "24Protect" and "HolidayGuard". This is because customers are indemnified against the loss of non-refundable deposits due to cancellation. In our model, we do not consider penalty on the customers whenever they cancel their orders.

Generally, there is a dearth of literature considering the impact of demand cancellation on the optimal ordering policy of the inventory model. Cheung and Zhang (1999) study the impact of cancellation of customer orders via assuming an (s,S) policy and Poisson demands. They develop a Bernoulli type cancellation behaviour in which a reservation will be canceled with probability p. In addition, the timing to cancellation is considered. In particular, they show that a stochastically larger elapsed time from reservation to cancellation increases the systems penalty and holding costs. Yuan and Cheung (2003) consider a periodic review inventory model in which all demands are reserved with one-period leadtime, but orders can be canceled during the reservation period. They formulated a dynamic programming model and show that the order-up-to policy is optimal. You (2003) investigates a joint ordering and pricing problem for a single period model in which the system sells perishable products over a short sales season. He proves that the optimal ordering policy has an order-up-to structure. You and Hsieh (2007) develop a continuous time model to determine the production level and pricing decision by considering constant rate of demand cancellation. They formulate a system of differential equations for inventory level so that holding and penalty costs can be calculated. However, they did not address the impact of cancellation on the optimal cost of managing the system.

On the other hand, supply uncertainty is one of the common supply chain glitches whereby the quantity delivered by the supplier may be deviated from the original order. Such loss of items can be due to strikes, misplacement of products, or incorrect shipment quantities on the supplier's side. The topic of supply uncertainty has been included in stochastic inventory models in the following ways. Wang and Gerchak (1996) use the concept of random yield to model supply uncertainty. In their work, random yield is the fraction in which the manufactured quantity turns out to be usable. They derive the optimal policy for the inventory model under the influence of both variable production capacity

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and random yield. They study the optimal policy for the finite and infinite horizon model and the structure is not an order- up-to policy. Güllü et al. (1999) consider the supply uncertainty using Bernoulli process in which either the supply arrives or not. In other words, the quantity ordered either arrive or do not arrive. They study a periodic review model and obtain a non-stationary order-up-to policy. However, they assume that the demand in each period is deterministic. Li and Zheng (2006) characterize the structure of the optimal policy that jointly determines the production quantity and the price for each period to maximize the total discounted profit, in the presence of random yield and stochastic demand. Using price-dependent demand function which is additive, they show that a threshold type policy is optimal. Furthermore, the optimal price decreases in the starting inventory. Following closely to the work of Güllü et al. (1999), Serel (2008) develops a single period model to identify the best stocking policy for a retailer with uncertain demand and supply. Finally, Liu et al. (2010) consider the impact of supply uncertainty on the firm's performance under joint marketing and inventory decisions. They develop a single period model showing that reducing variance of supply uncertainty improves the firms' profit. Rather than focusing on the structure of the optimal policy, their aim is to derive managerial insights based on firm's willingness to pay for reducing supply uncertainty.

In this paper, we will consider the effect of supply uncertainty or yield on the optimal inventory policy with demand cancellation. To our best knowledge, no research has been done to address demand cancellation and supplier uncertainty concurrently. One main contribution of our work is to show that the optimal inventory policy with supply uncertainty shares similar structural properties as that with supply certainty for both the finite horizon case and the infinite horizon case. In particular, we show that due to the presence of supply uncertainty, the optimal inventory policy is characterized by a re-order point. Furthermore, we show that this re-order point is independent of the supply uncertainty factor. Gerchak et al. (1988) derive a similar policy which they call it the "critical point" policy. Their work features a production model with yield uncertainty and stochastic demand. However, their objective function is the profit function. Wang and Gerchak (1996) also show a similar inventory policy but their critical point is dependent of supply uncertainty ("random yield factor"). We also establish the fact that the expected cost of managing a firm is higher when its supply uncertainty has a relatively larger variance. Interestingly, we show that a more variable yield distribution does not necessarily increase the optimal ordering quantity due to the influence of cancellation. Similarly, we also prove that it is less costly if the firm is to reduce the variance of cancellation behaviour. However, reducing the frequency of demand cancellation does not necessarily translate to cost reduction for the firm. Therefore, we can only develop a bound on the difference between the optimal cost in the presence of differing cancellation behaviour. It turns out that the bound is proportional to the difference between the mean number of items not eventually canceled.

The rest of the paper is organized as follows. The model and notations are developed in Section 2. Section 3 presents a model for the single period. The convexity for the optimal cost is established and the optimal ordering level is derived. We show that reducing the variance of either the distribution of yield or the distribution of demand cancellation leads to a lower cost of managing the supply chain. Section 4 is similar to Section 3, but explores the finite horizon case. In Section 5, we discuss the infinite horizon model and solve the optimal policy. We also show that the cost of managing a firm is higher when the distributions of demand cancellation and yield are more variable in the sense of convex ordering. In Section 6, we provide numerical evidences to our observations made in earlier sections. We also propose an algorithm to obtain the optimal ordering quantity. An example is given using our proposed algorithm. Finally, we provide a concluding note with some possible extensions to this work in Section 7.

2. Model

Consider a periodic review inventory system. All demands are made through reservations. Demands reserved in the previous periods are supposed to be fulfilled in the current period. However, due to customers' indecisiveness, demands may be canceled. Suppose $\mathbf{N}$ is the set of non-negative integers. Let D_n be the demand that is reserved during period $n \in \mathbf{N}$, and let R_n be the ratio of the demand reserved during the previous period that is eventually not canceled during period n. Finally, $1-\theta_n$ is the supply uncertainty factor, where θ_n represents the ratio of items that is received after an order has been made during period n. If production is involved, then θ_n can be interpreted as the yield ratio during period n. If $\theta_n = 1$ with probability one, then there is no supply uncertainty. We assume that $\{D_n : n \in \mathbf{N}\}$ is a sequence of i.i.d demand random variables with a common distribution $H(x)$ (with $H(0) = 0$ and $H(\infty) = 1$), density function $h(x)$, and mean ζ. We let $\{R_n : n \in \mathbf{N}\}$ be a sequence of i.i.d ratio random variables whose c.d.f is $G(x)$ (with $G(0) = 0$ and $G(1) = 1$), density function $g(x)$, and mean γ. Similarly, we let $\{1-\theta_n : n \in \mathbf{N}\}$ be a sequence of i.i.d supply uncertainty in each period. If $\theta_n \overset{d}{=} \theta$ is a random variable, then we write its c.d.f as $F(x)$(with $F(0) = 0$ and $F(1) = 1$) and its p.d.f as $f(x)$.

We also make the assumption that cancellation ratios R_n, demands D_n, and supply uncertainty factors $1-\theta_n$ are independent of each other. All the unfulfilled orders are backordered. The inventory holding cost (h) and penalty cost (p) are both incurred on a per unit time basis. At the beginning of a period, the inventory level is x and the demand reserved in the previous period is $z(>0)$. Let y be the decision variable representing the order quantity made at the beginning of the current period. Define $[x]^+ = \max\{x, 0\}$ and $[x]^- = \max\{-x, 0\}$. The leadtime is assumed to be zero. Suppose θ is the current period supply uncertainty, then θy is the amount that is available to fulfil the demand, thus the one period cost can be written as

$$\begin{aligned}\varphi(x,y,z) &= hE[x+\theta y - zR]^+ + pE[x+\theta y - zR]^- \\ &= h\int_0^1 \int_0^{\frac{x+sy}{z}} (x+sy-zt)dG(t)dF(s) + p\int_0^1 \int_{\frac{x+sy}{z}}^1 (zt \\ &\quad - x - sy)dG(t)dF(s). \qquad (1)\end{aligned}$$

Following Yuan and Cheung (2003), we let $C_n(x,z)$ be the optimal total cost from period n to period 1 given that the initial inventory level is x and the demand reserved in period $n+1$ is z. We define the cost when there are no periods left to be $C_0(x,z) \equiv 0$ for all x, z. Suppose D is the demand that arrives during period n, and $\alpha \in [0, 1)$ is the discount factor. Then,

$$C_n(x,z) = \min_{y \geqslant 0}\{\varphi(x,y,z) + \alpha E_D E_{\theta,R} C_{n-1}(x+\theta y - zR, D)\}. \qquad (2)$$

Set $\Phi_n(x,y,z) = \varphi(x,y,z) + \alpha E_D E_{\theta,R} C_{n-1}(x+\theta y - zR, D)$. From (1), we have $C_n(x,z) = \min_{y\geqslant 0}\Phi_n(x,y,z)$.

3. Single period analysis

In this section, we shall explore the impact of supply uncertainty on the ordering policy for the single period case. We assume that x denotes the inventory level and z denotes the demand reserved in the previous period. Differentiating (1), we obtain

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