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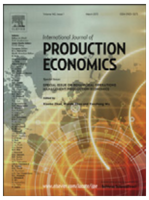

Tactical inventory and backorder decisions for systems with predictable production yield

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ABSTRACT

We consider a manufacturing system with stochastic demand and predictable production yield. The manufacturer has predetermined prices and limited production capacity in each period. The manufacturer also has the option to save some inventory for future periods even if there is demand in the current period. The demand that is not met is lost or may be backordered for only one period. Our objective is to maximize the expected profit by choosing optimal produce-up-to level $(\overline{Y_t}^*)$, save (S_t^*) and backorder quantities (B_t^*) in each period t. We formulate this problem as a Markov Decision Process where the state of the system is represented by the net inventory and the yield rate. We show that a modified order-up-to policy $(\overline{Y_t}^*, S_t^*, B_t^*)$ is optimal in each period t. We also perform computational analysis to examine the effects of production yield on the optimal decisions.

1. Introduction

In modern production systems, due to highly competitive markets, it is extremely essential to follow and optimize all stages of production. From raw material procurement to customer delivery, all processes have to be designed and carried out very carefully. Hence, a vast number of studies were conducted on supply chain systems, many of which are about inventory control systems. Inventory related costs constitute a significant portion of total supply chain costs explaining the particular interest in inventory problems.

Demand uncertainty is one of the main problems faced in inventory systems, and the prevalent tradeoff is between lost (or backordered) sales and inventory holding costs. Almost all inventory management strategies are developed to minimize costs by controlling this tradeoff. In traditional inventory control systems, the manufacturer meets the demand with all products at hand. However, sometimes it may be more profitable not to sell all items available and allow lost sales. That is especially true for systems with varying prices and production costs. Rationing policies have been introduced as alternative inventory control policies to consider this fact. With these policies, the manufacturer has the option to reserve some of the products for future periods even if it is possible to sell these items in the current period.

In this study, we consider a manufacturer with production capacity restrictions that produces a single item to serve a single customer class. The manufacturer has the option to save some inventory for future use and backorder some demand to be met in the following period. The prices for all periods are set at the beginning of the time horizon. However, these prices are not known by the customers beforehand. Hence, the customers do not act tactically. This is a general assumption considered in recent studies on rationing such as Federgruen and Heching (1999), Chan et al. (2006), and Duran et al. (2007). Different than the previous studies, there is a predictable production yield rate in each period in our study. In each period, the manufacturer has to decide how much to produce, save and backorder.

Our policies may be adopted successfully by a manufacturer introducing a new genuine product to the market. In such a system, the manufacturer is the sole monopolistic supplier and can decide prices over a time horizon. There are no substitutes and customers may accept backordering for a limited time. Also, the firm may reserve products for future use if there are restrictions such as capacity deficiency. Change in the production yield and production costs can be forecasted as they are affected by the learning effect and seasonality. In this framework, we focus on the characterization of the optimal inventory policy and the corresponding production quantities. As a real life example, we can consider the time Apple introduced iPhone to the market. Before the product launch, the introductory price and probably prices for the following few months were already decided by the firm. Introductory price was planned to be a bit higher than the following period prices since people had waited for the product for months already and they were much more eager to buy

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initially. Also, they easily accepted backordering. It is obvious that customers will accept backordering up to a specific time, for example one month. Last, the firm probably had a production yield trend affected by the learning effect as we have in our model.

Our findings indicate that using tactical instruments that we discuss (saving inventory for future demand and backordering demand to satisfy in the future) may provide substantial benefits to the companies, especially when the prices are nonstationary, and the capacity is limited due to physical constraints and imperfect production processes. In such settings, firms should allocate their limited production to customers considering the effects of changes in their costs and prices through time. We believe that such environments are frequently observed, especially in new product launches. Our computational analysis reveals that the improvement due to these instruments may exceed 25% when compared to the traditional inventory management policies. However, it should be noted that the success of tactical inventory management depends heavily on the firm's ability to forecast the prices/costs and production capabilities for the planning horizon.

The remainder of this study is organized as follows. In Section 2, we review the related literature and discuss recent studies about rationing and yield. We introduce and analyze our model in Section 3. In Sections 4 and 5, we discuss save-inventory and backlog-demand models, respectively. We discuss our findings from computational analysis in Section 6 and share some insights. Finally, we present our findings briefly and present some extension ideas in Section 7.

2. Literature review

We discuss recent studies related to our study in two main streams; discretionary sales and production yield. Although there are numerous studies conducted on inventory theory, only a few of them consider discretionary sales. Scarf (2005) focuses on an inventory planning problem in a multi-period, single-item production system with production capacity limits and fixed production setup costs. He shows that the optimal inventory policy is of (s, S) type. He also demonstrates that the optimal discretionary sale amount is dependent on the realized demand. Hence, the manufacturer has to wait for the demand realization before determining the amount of discretionary sales.

Chan et al. (2006) integrate pricing and production decisions in a similar setting and focus on partial planning strategies; delayed production strategy and delayed pricing strategy. In the former strategy, the pricing decision is made at the beginning of the time horizon and the production decision is made at the beginning of each period. Different than Scarf (2005), Chan et al. (2006) show that in delayed production strategy, the optimal policy is independent of the realized demand and the initial inventory level.

Duran et al. (2007) discuss inventory policies in a multi-period, single-item system with two customer classes and rationing among these customer classes. Customer classes are differentiated according to their willingness to pay and wait. There is a production capacity for each period and the unmet demand may be backordered for one period. Prices are determined at the beginning of the horizon and production decision is made in each period. The authors show that a modified order-up-to policy is optimal and backorder and reserve decisions are independent of the realized demand.

Smith et al. (2009) consider a joint pricing and inventory planning problem in a multi-period, single-item system with both capacity and inventory constraints. The authors aim to determine the optimal price, production quantity and sales amount for each period. The problem is solved exactly with an exponential demand function for a single period using a linear programming model and using this exact solution, a dynamic programming solution is developed to solve the multi-period model. This paper extends Chan et al. (2006) by solving pricing and production problem simultaneously.

Yan and Liu (2010) determine replenishment and discretionary sales jointly in a system with limited capacity, uncertain demand, lost sales and random yield. The objective is to minimize the total cost by choosing optimal replenishment and discretionary sales policy. The main difference in our study is that we consider backordering in addition to lost and discretionary sales. We also incorporate nonstationary price trends, and through a detailed numerical analysis we observe that tactical inventory management improves the system performance significantly.

Production yield has been studied extensively in literature. Yano and Lee (1995) present a detailed literature review on this area. Henig and Gerchak (1990) provide an extensive analysis of a periodic-review single-item production system with stochastically proportional yield. The authors provide analysis for single-period, finite-horizon and infinite-horizon models, and show that the infinite horizon order point is lower when yield is uncertain. They also show that the order point is independent of yield in a single-period model. We have similar results indicating that the yield rate in current period does not have an impact on the optimal policy of the current period.

Wang and Gerchak (1996) consider a production planning problem in a periodic review system with unpredictable capacity, random yield and stochastic demand. They discuss simultaneous effects of uncertain capacity and yield on the lot sizing decision. They prove that the optimal policy is characterized by a single reorder point in each period, but is not of an order-up-to type. Bollapragada and Morton (1999) present three heuristics for a single-item, periodic-review inventory model with stochastically proportional yield and stochastic demand where unsatisfied demand is backlogged.

Grosfeld-Nir et al. (2000) include inspection costs to a "multiple lot sizing production to order" model with random production yield. Li et al. (2008) discuss an infinite horizon decision problem in a single-stage, single-item, periodic review system. Production yield and demand are uncertain in the system. There are other studies on production yield in production systems, however, to the best of our knowledge none of them except Yan and Liu (2010) considers discretionary sales.

3. Main model and assumptions

We consider a single product sold by a single manufacturer over a multi-period time horizon, where the manufacturer has limited production capacity in each period. The manufacturer serves a single customer class and makes decisions over a multi-period time horizon, $t=1,2,\ldots,T$, with T representing the end of the horizon. Production in each period t is limited by the capacity, q_t, and the manufacturer pays a production cost, k_t, per each unit produced. Inventory holding cost is linear, and a charge per unit, h_{t+1}, is incurred to carry inventory from period t to $t+1$.

The manufacturer has predetermined prices, p_t, that may be different in each period. It has three options to handle a demand occurrence: (i) satisfy the demand from the current inventory, (ii) satisfy the demand from the next period's production (that is, backorder the demand at the current period and satisfy it definitely in the next period) and (iii) lose the sale. If the first option is chosen, the manufacturer not only makes a revenue (p_t) but also saves from carrying one unit of inventory to the next period (h_{t+1}), and moreover saves from the unit lost sales cost ℓ_t