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Demand switching criteria for multiple products: An inventory cost analysis

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ABSTRACT

In this paper, we consider the problem of demand switching and show how a firm can take advantage of the risk-pooling effect to gain more profit. We examine the case of three products under various switching criteria; a model based on the heuristic approach is developed to determine the switching paths and the corresponding switching rates that yield the optimal profit. A constrained model with limited amount of the switched demand is also developed. In general, the profit increases as a result of higher profit margin or smaller demand variation and correlation. Our result indicates that the profit does not necessarily increase as the switching rate increases; in some cases the profit may even decrease as a result of demand switching. Numerical examples are also included to illustrate the derived models. The developed analytical approach may help practitioners to gain more insight in demand switching and facilitate inventory related decision-making process as well.

1. Introduction and literature review

Uncertainty of products' demand is a common source of variability which often calls for additional attention in the decision making process regarding inventory and distribution systems. Such variability or uncertainty in the level of demand put practitioners in a dilemma: On the one hand, they wish to maintain a high inventory level to satisfy customers' demand and generate revenues from sales. On the other hand, they want to reduce costs associated with high inventory levels; carrying high level of inventory for products with relatively small chance to be demanded is considered a risky investment. Indeed, demand uncertainty accompanied by replenishment lead-time in a declining price environment makes it even arduous in managing inventory [1,2].

Firms have performed various inventory strategies to ease the burden associated with demand variability [3]. Among them, a popular approach is to centralize or consolidate inventory of several locations, i.e., inventory pooling, to take advantage of the risk-pooling effect. Inventory locations may be associated with different geographical sites, different products, or different customers. For example, Maister [4] asserted that the total inventory in a system is proportional to the square root of the number of locations at which a product is stocked; he showed how inventory centralization leads to the minimum inventory holding policy. This strategy may reduce total demand variability and result in improved system performance. Since Eppen [5], inventory pooling has been an important theme in operations management. Early studies concerning the fundamental effect of reducing inventory through pooling demands for different products include [6–11]. These studies demonstrated the reduction in inventory due to centralization. However, a counterexample in which a centralized configuration requires a higher inventory level is described in Chen and Lin [12]. Eynan [13] considered a profit-maximizing problem where markets have various selling prices as well as diverse shortage penalty costs, and showed that centralization is recommended. He also mentioned that managers should not be afraid of 'supply cannibalization', where customers from low-paying markets arrive early causing the firm to fail to satisfy later demand from high-paying markets. The presented ideas also provided a foundation for research on distribution, for example, for the purposes of distribution channel and network design [14–16].

When multiple products are offered, firms can also capture the advantage of the risk-pooling by using common components for different products and employ the assemble-to-order strategy [8,10]. Many studies have examined aspects such as demand distributions and correlations, cost structures, time horizons, etc.; they determined a number of factors that represent bounds to a commonality strategy. However, some demand conditions can also reduce the savings through pooling substantially. Gerchak and Mossman [17] showed that under certain demand conditions risk pooling, i.e., demand aggregation through the use of common parts, does not lower physical inventory but rather increases it. Eynan and Rosenblatt [18] noted that a common component may be more costly than each of the components it replaces due to its wider functionality. Nevertheless, even a more expensive component may still result in a cost reduction. It is worthwhile to note that commonality among components may introduce a correlation between the demand patterns of the components [19,20]. Despite this resulting challenge in estimating performance measures of cost and the order fill rate [21], sharing components by several products

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may still reduce the variability of demand (for components), which eventually can reduce inventory costs and improves the firm's performance.

In addition to the above approach of utilizing internal component commonality and take advantage of the risk-pooling effect, a recently introduced approach is demand reshape/switching which focuses on external consumers' demand [22]. It seeks to persuade some of the customers to purchase another (usually a substitute) item instead of the original item they had in mind. This can be achieved through displaying posters of products in front of the stores, or offering discounts, etc., to make customers more aware of the available substitute item. The cost of such marketing effort can vary widely. These marketing practices make some customers switch to another item and apparently change the demands for the two items. Consequently, these practices increase the demand mean and variability of one product while reducing them for the other product. That is, changing the choice of some consumers reduces the sum of product demand variability and consequently leads to a reduction in overage and underage costs and improves performance.

Analysis of the product substitution, where customers may switch to an available item upon stockout of another, appears in a number of papers starting with McGillvray and Silver [23] who showed that substitution can reduce the total cost of holding and shortage. Parlar and Goyal [24] later considered profit maximization in the case without shortage cost and salvage value. Pasternak and Drezner [25] extended these works and examined the case of internal downward substitution where higher quality product can substitute low quality level product, but not vice versa; they suggested that substitution may result in reduced (per-unit) revenue. Other studies of downward substitution include [26]. Among the studies with two ways substitution, Parlar [27] studied a special case of perishable items where old items can substitute for fresh items and vice versa; others can be found in [28,29]. Smith and Agrawal [30] and Mahajan and Van Ryzin [31] deal with customer demand substitution where customers purchase the substitute product when their preferred product is out of stock. When a company offers two or more products, by reshaping demand, the total uncertainty of demand (measured as the sum of modified standard deviations) is reduced [22]. Consequently, the company is able to improve its profit; the aggregate product service level also increases while the individual product service levels remain unchanged. It was also found out that even a small proportion of switching customers results in an impressive profit increase [22]. In this case of demand switching, the retailer puts marketing effort in inducing customer substitution of the item with high variance by the item with low variance, even if the item with high variance is available.

On the other hand, Anupindi et al. [32], and Mahajan and Van Ryzin [31] focused on optimal stocking policies for a given portfolio of products, while Smith and Agrawal [30] dealt with optimal portfolio selection problem as well as optimal stocking problem. Later, Shah and Avittathur [33] focused on deriving a heuristic solution that can provide a reasonably good solution in a multi-product portfolio case. As aforementioned, commonality among components may introduce a correlation between the demand patterns of the components. Intuitively, demand patterns can also be correlated if the products are substitutable; customers perceived certain commonality among the products. As a result, this demand correlation has implications for the optimal inventory policy as well [30]. The results of the above works suggest that companies can enjoy most of the benefits of centralization and still maintain a decentralized configuration by attempting to use common components and/or demand reshape. As both approaches rely on the risk-pooling effect to gain benefits, Eynan and Fouque [34] explored the efficiencies of the two approaches; they compared performance and also investigated the potential benefits of employing both simultaneously.

In this study, we consider a firm that sells multiple products with correlated demand; we intend to answer the important question of how the managers can take advantage of the risk-pooling effect to increase the profit through demand switching. The challenges in this decision lie in 'how' and 'how much' to switch. The issue of 'how' refers to the decision on the selection of products to switch to and from, that is, the selection of the switching path, while the issue of 'how much' refers to the amount of the switched demand, that is, the decision of the switching rate of the original demand. Without loss of generality, we consider the problem where three products (product A, B, and C) are offered. In addition, it is assumed that product A (C) is with the highest (lowest) demand variation. Intuitively, one may consider either the 'downward switching', that is, to convince customers to switch from the product with higher demand variation to that with lower demand variation, or the reverse direction of switching (i.e., 'upward switching'). Eynan and Fouque [22] showed that the 'downward switching' is more beneficial. As suggested, we consider the following criteria of switching: The first criterion of switching where triple-path switching is considered is defined as 'Full Downward Switching'. If double-path switching is considered, the switching pattern can be Sequential, Merge, or Burst. Practitioners could also consider single-path switching; there are three possible scenarios in this type of switching. These various types of demand switching are illustrated in Fig. 1. Note that in our study, switches take place due to customers' change of preference when the inventory of their originally intended item may still be available.

It is known that various demand switching rates among the products result in different cost/profit performance; we intend to examine this analytically in this study, that is, to develop an analytical framework to access the risk-pooling effect through demand switching. Specifically, three main questions are to be answered: (1) What are the switching paths and the corresponding switching rates that yield the maximum profit? (2) Given a limited amount of demand available for switching (e.g., due to the constraint in transportation or storage), how would one determine the optimal assignment of the switched demand for a specific switching criterion? (3) For a specific switching criterion, what is the impact of demand correlation on the profit? The answers shall facilitate the decision making process, for example, trade-off analysis with switching cost; the analytical results are also fundamental when more product types are considered in future studies.

As can be seen, when multiple products are considered, however, none of the previous studies addressed the specific problem we consider even though the risk-pooling effect was well documented in an abundant body of research. Our questions of interest are not fully answered by existing literature and this research topic surely deserves to be explored. The remaining sections of the study are structured as follows: In the next section, assumptions and definitions are presented. Our proposed demand switching models are then developed and analyzed; the heuristic approach is proposed to find the optimal switching paths and calculate the corresponding switching rates. We also discuss the assignment of switched demand in the case of limited switched demand. The developed models are later illustrated and evaluated with numerical examples. Last, we conclude our study; suggestions for future research along with managerial insights are also provided.

2. Basic definitions and assumptions

In this section, we first present the basic definitions and assumptions. The following definitions will be used throughout the study:

p_i = selling price per unit of product i,
c_i = purchase cost per unit of product i, and
v_i = salvage value per unit of product i.