Managing Demand and Supply for Multiple Products through Dynamic Pricing and Capacity Flexibility

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Extended Abstract for INFORMS M&SOM Annual Conference 2010, Technion, Haifa, Israel

Virtually all manufacturing and service industries are susceptible to periods of supply and demand mismatches. Due to capacity limitations and demand uncertainties, firms producing multiple products may frequently encounter instances where one of their products faces shortages while the other has excess inventories. In order to alleviate the level of such inventory mismatches, several tools may be utilized to either alter supply or demand. Our focus in this paper will be a joint analysis of two of these mechanisms, namely, dynamic pricing and capacity flexibility. We consider a firm that produces two substitutable products with price-correlated demands, implementing a dynamic pricing strategy. Further, the firm employs capacitated product-dedicated resources for each product as well as a flexible resource that may be used to produce either product. We are interested in the firm's optimal pricing and production policies and how the availability of a flexible resource influences the dynamic pricing strategy.

In the last decade, many industries have seen investments in flexible manufacturing systems that enable the production of multiple variations of products in the same factory. This enables the product mix to be easily altered if demand for one product increases while demand for another decreases. However, prices may also be dynamically decreased or increased in response to demand fluctuations. For example, many LCD TV manufacturers make multiple display sizes in the same factory. During the “great recession” of 2009, demand for larger sized (42 inches and above) TVs have slowed down in the U.S. as consumers trimmed their budgets and preferred smaller sized and lower priced models. Thus a manufacturer that produces multiple models of different sizes has the following choices to respond to this change in demand: 1) It can decrease the price of larger sized models to stimulate more demand, 2) it can switch more of their production to smaller sized models (e.g., 32, 37 and 40 inch) or a combination of the two policies. Further, it is estimated that the increased demand for smaller sized TVs as a result of the economic downturn is temporary and as the world emerges from the recession, demand for larger sizes will again outpace the smaller size TVs. Therefore, an important consideration is that the manufacturers would like to maintain a reasonable price difference between the different size models (e.g., it may not be a good strategy to drastically reduce the price of 46 inch TVs below those of 37 inch TVs to respond to short term demand fluctuations and inventory excess as this will influence customers’ perceptions of product valuations in the long run). This motivates the problem we address in this paper: How should a firm manage its simultaneous production and pricing policies for multiple products using flexibility?

Specifically, several interesting questions arise when dynamic pricing and capacity flexibility are considered simultaneously. First, we are interested in answering (i) how should the firm decide on the price charged for each item, (ii) how much of each product should the firm produce and (iii) how should the flexible resource be allocated among products in a given period. Hence, our first goal is to characterize the optimal dynamic pricing and replenishment policy for multiple products over multiple periods in the presence of capacity limitations and the availability of a flexible resource.

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Second, we are interested in understanding the influence of the availability of a flexible resource on the firm's pricing decision. That is, we would like to compare the optimal pricing policy of a firm, which may utilize flexible resources to that of a firm, which employs only product-dedicated resources. Third, we aim to identify the economic benefits obtained by applying each tool jointly and separately and understand (i) whether dynamic pricing and capacity flexibility are substitute approaches, i.e. if the economic benefits obtained by one tool diminishes with the utilization of the other, (ii) whether applying one tool dominates the other, and (iii) the circumstances under which dynamic pricing may contribute to profitability more than capacity flexibility, and vice versa.

We formulate the problem as a finite horizon stochastic dynamic program. At the beginning of each period, the manufacturer reviews the current inventory positions and decides on the optimal production quantities and the prices to charge during the period. We assume the demands for both items are correlated and represented by a linear stochastic additive demand model, which has been prevalent in related literature. Since the products are substitutable, demand for an item is decreasing in its own price and increasing with the price of the other item. Further, we assume that a price change on an item influences its demand at least as strongly as it influences the demand for the other item, i.e., the income effect is at least as strong as the substitution effect, and that both products experience identical cross-price elasticities. These assumptions on demand parameters, besides their economic justification, also result in a concave revenue function. Production decisions are restricted by the available capacity. Dedicated capacity may only be assigned exclusively for the corresponding product whereas the flexible capacity may be assigned entirely to any one item or partially shared by both items during the period.

Our first contribution in this paper is to provide a full characterization of the structure of optimal production and pricing decisions. We show that the optimal production policy is of a modified base-stock type and exhibits distinct forms across several regions of the state-space. To assist us in our representation of the optimal policy, we classify the initial inventory level of a product as “overstocked” if the item requires no further replenishment, as “moderately understocked” if the available capacity is adequate to bring the inventory to a desired level, and as “critically understocked” if capacity is restrictive to reach the desired inventory level.

We find that when both products are moderately understocked, it is optimal to produce both products up to a uniquely defined base-stock level. If one item is overstocked while the other is moderately understocked, the optimal policy is to bring the inventory of the understocked item to a level that is lower than the base-stock. The reason is twofold. First, as we will shortly reveal in the discussion of the optimal pricing policy, an overstocked product, e.g., product 2, results in a price decrease for that item which in turn increases its demand and decreases the demand for item 1 which further decreases the base stock for item 1. Second, an overstocked item 2 reduces the potential work load on the flexible resource for that item and increases the availability of the flexible capacity for item 1 in future periods. This allows for fewer units of item 1 to be produced in the current period. If, on the other hand, one item is critically understocked while the other is moderately understocked, it is optimal to use all flexible capacity for the critically understocked item and bring the inventory of the other item to a level higher than the base-stock level due to similar but reverse dynamics. When one item is overstocked while the other is critically understocked, it is optimal to raise the inventory position of the critically understocked item as much as the flexible and dedicated capacity permits. When both items are critically understocked, it is optimal to allocate the flexible capacity in such a way that the share of flexible resource an item receives is decreasing with its own inventory and increasing with the other item's inventory.

Regarding the optimal pricing policy, we show that a list price is charged for an item if it is moderately understocked. If an item is critically understocked, then a price markup that depends on both inventory levels is applied. When an item is overstocked, a price discount that depends on both
inventory levels is given. Furthermore, we show that when inventory levels for both items are critically understocked and when the flexible capacity is simultaneously shared between products, the existence of the flexible resource leads to an optimal pricing scheme that maintains a constant price difference between products. At such instances, dynamic pricing only adjusts the overall level of demand for both products but does not attempt to shift demand from one product to another, while mismatches between the desired and actual inventory level of products are restored solely by the availability of flexible capacity.

Hence, one of our major findings is that the availability of a flexible resource helps maintain stable price differences across items over time even though the price of each item may fluctuate over time. This result has favorable ramifications from a marketing standpoint as it suggests that even when a firm applies a dynamic pricing strategy, it may still establish consistent price positioning among multiple products if it can employ a flexible replenishment resource. We also perform several numerical studies to visualize how the availability of a flexible resource influences the firm's optimal pricing strategy. We construct three problem instances with a gradually increasing share of a flexible resource in the firm's capacity portfolio and demonstrate the price-difference stabilizing effect of flexible resources as we have shown analytically in the analysis of the optimal pricing policy.

In addition to the optimal policy structure itself, we are also interested in how changes in various problem parameters affect the optimal policy. Specifically, we analytically explore the sensitivity of the optimal policy to (i) cost parameters including the production, holding and backorder costs, (ii) capacity parameters, and (iii) demand parameters including demand intercepts, individual and cross-price elasticities. For example, we consider how the production cost of an item influences the optimal prices and modified base-stock levels. Intuitively, as it becomes more costly to produce product 1, the selling price for this item would increase, reducing the demand and therefore its modified base-stock level. However, it is not obvious how the price of item 2 is affected. On the one hand, a resulting price increase for item 1 strengthens the demand for item 2 which may drive the prices for this item higher. On the other hand, the cost increase and the resulting price increase for item 1 decreases item 1's demand, potentially allowing more flexible capacity to be assigned to item 2, increasing item 2's availability and thereby decreasing its price. Our analysis indicates that the former argument dominates unless both items are critically understocked and are receiving a share of the flexible capacity, for which the second argument prevails.

Finally, we compare the economic benefits of implementing dynamic pricing and capacity flexibility individually and simultaneously. We find that the two mechanisms may be viewed as substitute, but not fully interchangeable approaches. Confirming the intuition, we find dynamic pricing to be a more effective tool when both items are either under- or over-stocked. Such instances may be observed frequently when demand uncertainties for the products are positively correlated. On the other hand, we find flexible capacity to be the more effective tool when there is a negative correlation between the demand uncertainties, which yield to instances with inventory mismatches where one item is well stocked and the other having limited inventories.

To conclude, in this paper, we study a joint mechanism of dynamic pricing and capacity flexibility to mitigate demand and supply mismatches across multiple products. By considering a firm that produces two products with correlated demands utilizing capacitated product dedicated and flexible resources, we characterize the structure and sensitivity of the optimal production and pricing decisions. We find that the presence of a flexible resource in the firm's capacity portfolio helps maintain stable price differences across items over time. This enables the firm to establish consistent price positioning among multiple products even if it uses a dynamic pricing strategy. Hence, our results indicate that the use of flexibility in conjunction with dynamic pricing not only has the potential to improve profits significantly, but also prevents otherwise optimal pricing paths to impair consumers perception of product valuations in the long run.