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Coordinating pricing and production decisions for multiple products ☆

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ABSTRACT

We consider a dynamic problem of joint pricing and production decisions for a profit-maximizing firm that produces multiple products. We model the problem as a mixed integer nonlinear program, incorporating capacity constraints, setup costs, and dynamic demand. We assume demand functions to be convex, continuous, differentiable, and strictly decreasing in price. We present a solution approach which is more general than previous approaches that require the assumption of a specific demand function. Using real-world data from a manufacturer, we study problem instances for different demand scenarios and capacities and solve for optimal prices and production plans. We present analytical results that provide managerial insights on how the optimal prices change for different production plans and capacities. We extend some of the earlier works that consider single product problems to the case of multiple products and time variant production capacities. We also benchmark performance of proposed algorithm with a commercial solver and show that it outperforms the solver both in terms of solution quality and computational times.

1. Introduction

The topic of coordination between marketing and operations is of interest to both researchers and practitioners because it addresses key organizational issues that directly affect business performance. Shapiro [39] highlights key issues and poses many questions about how these two functions should collaborate. Decades after this paper, it appears that most of these questions still remain unanswered. In the current business environment, issues like capacity decisions, inventory deployment, price-promotion policy, and demand management are not just marketing or operational issues, but lie on the interface between the two. Karmarkar and Lele [24] highlight that ignoring these interactions can be extremely costly for a firm. They provide case examples to illustrate the problems that may occur when interactions go unrecognized. On the other hand, empirical studies show that a firm can improve its competitiveness and profitability [23], align its manufacturing priorities [22], and improve its delivery performance [38] by coordinating marketing and operational decisions.

Research on cross-functional interfaces and joint decision models is interesting because such research is useful for both tactical and strategic decisions. Moreover, a better understanding of interactions between different functions is useful for setting goals, adjusting performance measures, changing behaviors, and even redesigning the organization structure. Thus, the impact of this research is much more than the obvious advantage of solving a specific tactical problem.

Most business problems span across multiple disciplines. Such problems, therefore, can best be solved by taking into consideration the variables of interest to all stakeholders. We believe that many solution approaches for operational issues may be extended to solve interdisciplinary problems and perhaps operation-marketing interface is a good starting point.

Joint pricing and production/inventory planning is a key interface between the two functions as these decisions directly affect the top line as well as the bottom line of a firm. Researchers have studied different models in this context. Most models consider these decisions with infinite capacity and model demand as a linear function of price. Some papers incorporate setup costs and only a few consider multiple products in their analysis. In many practical situations, it is common to produce multiple products (or brands) on the same production line which requires setups and has limited capacity. The problem of joint pricing decisions with setup costs and capacity constraints is of practical interest for manufacturing firms. However, to the best of our knowledge, this problem has not yet been addressed in the academic literature.

One of the co-authors has experience in managing the operations of a manufacturing facility that produced a range of consumer goods. This facility was owned and managed by a global

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company that manufactured and marketed these products. In this particular plant, the same production line was used to produce a variety of products including shampoo, moisturizer, skin cream, sunblock, and hand wash. These products have similar production requirements, but need a setup between production runs of any two products. Each product changeover requires extensive cleaning of the line to avoid contamination. For most products, some part of the initial production was discarded for the same reason, hence setup costs were significant. Because the products were not substitutes, there were no cross-pricing effects between products. Similar examples can be found in other industries, for example; textile, steel, paper, plastic molding, and packaging materials. Although the firm had implemented a Sales and Operations Planning process, the allocation of capacity to different products was a tedious and frustrating process. The complexity of the problem was compounded by the fact that different products were managed by different product managers who made independent pricing decisions. As a result, the 'agreed' demand and supply plan was nothing but a negotiated agreement. Such plans were not only suboptimal, but also unnecessarily consumed valuable management time. The motivation for this research stems from these and other similar situations experienced by the authors. We believe that there is a need to develop models and solution procedures that can solve such practical problems and can be adopted by practitioners.

In the computational portion of this research, we study a real world problem faced by a manufacturer of industrial gloves (hereinafter referred to as TIS). TIS has limited production capacity that may be used to produce different types of gloves. The customers are institutional buyers who make independent buying decisions. The gloves sell in different geographical markets and are not substitutable because of their unique features and applications. Furthermore, TIS may sell a product in different markets at different prices. For example, two buyers, one from the US and one from the EU, may purchase the same product at prices that are independent of each other. Each buyer makes her decisions independently, and no two buyers share the pricing information with each other. Because most of the products have specific applications and sell in different markets, the assumption of zero cross price elasticities is a fair assumption for this company's product portfolio. The firm divides its products into groups, where a marketing manager manages each product group. The marketing managers decide product prices and give a sales forecast for production planning. Our discussions with the management reveal that marketing managers review their pricing decisions every time a new inquiry comes from a customer. While quoting a price to a customer, they take into account, among other factors, the delivery requirements of existing orders. Thus, they tend to offer lower prices if they have fewer existing orders and vice versa. According to them, pricing decisions consume most of the of the management time during peak selling season as there are multiple rounds of price negotiation. The firm measures marketing performance on total contribution and sales volume. Likewise, product availability and operating costs are key performance indicators used for the manufacturing unit. TIS management realizes that such sequential decisions often result in sub-optimal profits, but they do not have a method for optimally allocating production capacity to different products. They are interested in having a framework that can be used for joint supply and demand planning. A related decision for multi-period problems is either to maintain a constant price or to change prices dynamically during the planning horizon. Many researchers study dynamic pricing in a retail environment and in the context of revenue management. Few papers consider the effect of dynamic pricing on a manufacturing firm's profit.

This paper makes several contributions to the literature. First, it fills a gap in the academic literature by solving the joint pricing and production planning problem for multiple products over multiple periods with time variant setup costs and capacity constraints. It also shows how a restriction of this problem can be (re) formulated and solved as a nonlinear resource allocation problem. The algorithm developed for this paper finds optimal solutions equally well for both linear and nonlinear demand functions.

The remainder of the paper is organized as follows. Section 2 presents a brief review of the literature on pricing and lot-sizing problems. Section 3 formally defines the problem and then presents the mathematical formulation. Section 4 describes the solution approach and provides a detailed description of the proposed solution procedure. Section 5 describes some properties of optimal solutions, provides numerical examples based on real world-data from a manufacturer of industrial gloves, and benchmarks performance of proposed algorithm with commercial solver KNITRO 9.1.0. Finally, Section 6 concludes with a summary of the contributions of this research and discusses future extensions. All proofs and pseudo-codes of proposed algorithms are provided in the Appendix section of this paper.

2. Literature review

The earliest papers that address joint pricing and lot-sizing decisions consider the single product problem in an economic order quantity (EOQ)-type setting. Seminal papers include that of Whitin [45] and Wagner and Whitin [44] who introduce price as a decision variable in lot-sizing decisions and prove the well-known planning horizon results. They also consider variations of the basic model with demand and cost functions changing across time periods. Thomas [42] builds further upon the planning horizon results of Wagner and Whitin [44] and shows that prices in periods between setups can be optimized independently. In his model, setup, variable, and inventory holding costs may differ from period to period. Kunreuther and Richard [26] study the same problem and show that coordinated decisions result in higher profits for a firm.

Since these early papers, many researchers have contributed to the literature by considering different variations of the problem. For example, some consider a single product while others incorporate multiple products in their models. Some allow prices to change dynamically whereas others choose a constant price for the planning horizon. Eliashberg and Steinberg [13], Chan et al. [7], Yano and Gilbert [46], Tang [41], and Chen and SimchiLevi [9] are excellent reviews of the joint pricing and production planning literature. It is evident from these surveys that only a limited number of papers include capacity constraints and few incorporate multiple products in their models. In this paper, we consider pricing and production decisions for multiple products while also incorporating capacity constraints and setup costs.

We now focus on papers that use discrete-time models with deterministic demand functions and a few other papers that are most relevant to this research. Porteus [36] determines a threshold demand beyond which price reduction coupled with investment in setup time reduction stimulates demand and increases profit. Morgan et al. [33] consider product portfolio decisions and present a multi-product model where one production line produces all products with the same frequency. They solve for a price vector that maximizes profit for a fixed production interval. Dobson and Yano [11] further extend this work to include decisions on which products should be made-to-stock and which ones should be made-to-order.

Kunreuther and Schrage [27] develop a solution procedure to solve a joint pricing and production problem for a single product whose demand is deterministic, seasonal, and decreasing in price. They allow the fixed ordering costs to vary over time and use a