Smart Pricing

A review of recent and seminal work linking pricing decisions with operational insights. Moritz Fleischmann, Joseph M. Hall and David F. Pyke

The past decade has seen a virtual explosion of information about customers and their preferences. Many companies have the ability to gauge customers’ willingness to pay for their products and can determine with some accuracy the effect of price changes on sales volumes. With Internet shopping, it is possible to effect such price changes at minimal cost for different customer segments and even for individual customers. Perhaps more enticing is the development of electronic shelf-labeling systems, which open the door to a remarkable array of possibilities for dynamic pricing in brick-and-mortar stores. The potential for increased revenue is huge.

At the same time, companies have taken major strides in understanding and managing the dynamics of the supply chain. Internally, many companies have implemented the tools and concepts of lean manufacturing. And externally, they have aggressively pursued supply chain initiatives, such as electronic procurement; vendor-managed inventory and collaborative planning; forecasting; and replenishment. The potential for cost reduction and service improvement is great.

Yet despite these potential benefits, there is a persistent dilemma. Pricing decisions have a direct, and sometimes dramatic, effect on operations and vice versa. This is vividly illustrated by the bullwhip effect, which can be initiated by price promotions (a classic 1997 paper by Lee et al. explains this effect). A more recent paper by Macé and Neslin (2000) provides new insight into consumer stockpiling in response to a promotion and deceleration (their willingness to reduce inventories in anticipation of a promotion). This insight has led many to suggest that firms should eliminate promotions in favor of “everyday low pricing” — evoking the disdain of their marketing colleagues. Also, the operations community has recently identified drivers for dynamic pricing, inspired by the widely acclaimed successes of revenue management in the airline industry (McCartney, 2000). These developments call for thorough integration of marketing and operations insights — which today still appears to be lacking. Conversations with a significant number of managers indicate that this integration is no more complete in industry than it is in academia.

Nevertheless, the linkage between pricing and operations is increasingly being scrutinized by academics and managers alike. For an extensive discussion of the literature, including technical aspects, see Rao (1993); Radjou et al. (2003); Chan et al. (in press); and Elmaghraby and Keskinocak (2003). In this article, we offer a snapshot of the work being done in this rich and evolving field, and we highlight different drivers for dynamic pricing strategies.

Revenue Management

Revenue management (or yield management) — the most mature area in dynamic pricing — is concerned with pricing a perishable resource in accordance with demand from multiple customer segments so as to maximize revenue or profit. To this end, prices are adjusted dynamically as a function of inventory level and time left in the selling season. Typical applications are in the airline and hospitality industries, where there is a fixed capacity that cannot be inventoried. In such applications, the cost side of the profit equation is largely irrelevant because the incremental cost of adding another passenger or filling another room is very low.

Research in revenue management has been impressive. McGill and van Ryzin (1999) provide a review of the literature and directions for future research; Boyd and Bilegan (2003) present an updated review with a focus on e-commerce applications. Revenue management has been the driving force behind many attempts to integrate pricing and operations.

Management practice and software solutions have likewise shown remarkable progress. The airlines’ successful use of revenue management is widely understood. Recently, similar concepts have been applied to manage rebates in car sales, contributing to, for example, $260 million of the $896 million first-quarter 2003 profits of Ford Motor Co. (Welch, 2003). Other examples in nontraditional industries include pricing of advertising time in the broadcast industry and capacity auctions in the natural gas pipeline industry (Secomandi et al., 2002).

Retail Markdowns

Retailers of seasonal goods — apparel, school supplies, Christmas toys — regularly face the perplexing problem of when, and by how much, to decrease prices as the

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season draws to a close. The underlying trade-offs are similar to those associated with the revenue management problem. In particular, product cost is largely irrelevant; the primary focus is on maximizing revenue from leftover goods.

A seminal reference for this research area is Gallego and van Ryzin (1994), which investigates static pricing policies that are much easier to implement than "jittery" dynamic prices. The authors find that the lost revenue due to static pricing is minimal, at least for the situations they investigated.

Another reference of interest about markdowns is Smith and Achabal (1998). Their model, which was tested and implemented at three retailers, sets prices optimally in conjunction with inventory policies, taking into account the impact of reduced assortment, price and seasonal changes on sales rates. Implementation was complex because of soft input data, existing management practices and related difficulties; thus, results were mixed. In one case, for instance, a revenue increase of only 1% was reported, although this represented a $15 million increase in gross margin. More recently, markdown analyses have been extended to multiple supply chain stages (Jorgensen and Kort, 2002).

Developments in software to manage markdowns have been more recent than in the field of revenue management. Marshall (2001) reports that retailers have experienced improvements in gross margins of 5% to 20% after implementing markdown optimization software, so we expect to see a rapid expansion of these implementations.

**Promotions and Dynamic Pricing**

Promotions are commonly used for new product introductions, but they are also frequently used with staple consumer goods such as tuna, soda and paper towels. It is this latter category that has generated most of the research. The literature suggests that price discrimination is a key driver of promotion offerings. For example, if customers differ in their brand loyalty, their access to information about current prices or their willingness to stockpile, periodic promotions may allow a firm to price discriminate profitably among these customers. However, price discrimination isn't the only motivation for price promotions; promotions that are less leaders also can drive store traffic. Neslin (2002) is a key reference, an excellent book that provides a full understanding of the reasons for promotions as well as an extensive review of the marketing literature in this area. Several recent papers merit further comment as well.

Kannan and Kopalle (2001) focus on Internet sales and generate a number of hypotheses about how consumers will react to dynamic pricing, both on the Internet and in physical stores. This paper explicitly considers the effects of consumer learning, reference price effects and consumer price expectations — all of which are largely ignored in the operations literature. Kopalle et al. (1999) conclude that higher-share brands tend to be overpromoted; while lower-share brands are not promoted frequently enough. They project profitability increases of 7% to 31% if their insights are employed. And as already noted in the introduction, Macé and Neslin (2000) provide evidence that promotions increase near-term sales but also decrease off-promotion sales. Unfortunately, the exact dynamics remain uncertain.

One open issue is the relationship of customer consumption and promotions. Our own research (Fleischmann et al., 2003) has investigated pricing policies for a firm facing a downward-sloping demand curve and an upward-sloping, concave consumption curve. The shape of this curve reflects the belief that consumers use more product when they have more. This consumption effect, if it is sufficiently strong, may sometimes justify periodic price promotions. However, in many cases constant pricing is preferable.

While these papers are representative of the marketing literature in the sense that they focus on consumer-behavior aspects of promotion, some work is beginning to include upstream supply considerations as well. Sogomonian and Tang (1993) study the coordination of promotion and production decisions and detail the increase in profit and decrease in inventory that result. Lyer and Yé (2000) study a three-level supply chain composed of retail customers, a retailer and a manufacturer, and they develop several interesting insights into promotions. For instance, if there is great uncertainty about the sales impact of promotions, it may be more profitable for the retailer not to promote. From the perspective of integrating operations and marketing decisions, the most interesting result is that as customer inventory-holding cost decreases, stockpiling increases. This suggests that retailers will promote less frequently, and less frequent promotions mean that stockpilers will purchase more with each promotion. Retailer profits increase in this scenario, but manufacturer profits decrease if the manufacturer is not made aware of the promotion schedule. Huchzermeier et al. (2002) model a case in which customers react to promotions by stockpiling and by switching package sizes, research incorporating the behavior of "smart" customers who calculate a per-unit cost of product and thereby choose package sizes optimally. Understanding the response of these smart customers can reduce inventory costs at the store and suggests that the retailer can benefit from offering a variety of product sizes.

The status of theoretical and empirical research suggests that promotions are heavily studied, but that there remain significant gaps in our knowledge. The research also reveals that managers rely on simple rules when making pricing and promotion decisions, although there are some notable exceptions. Software application developers are beginning to provide tools that can help managers add a level of science to the art of pricing.
Operations: Pricing, Lead Time and Capacity

Research that integrates pricing with management of lead time and production capacity can be divided into two segments. One integrates pricing concerns into the capacity-procurement decision, which reflects a long time horizon; the other focuses on a shorter time horizon, using pricing to make the best use of available capacity — akin to revenue management. The latter aims at smoothing out demand imbalances that are due to either structural seasonal patterns or short-term random fluctuations.

Three recent papers model the long-term capacity choice. So and Song (1998) study capacity expansion and pricing for a firm that uses delivery time guarantees as a competitive strategy. Along these same lines, Van Mieghem and Dada (1999) illustrate how competition, uncertainty and the timing of operational decisions influence capacity investment. Boyaci and Ray (2003) model pricing, delivery time and capacity decisions in conjunction with two substitutable products. They develop insights into the relationship between the relative cost of capacity for the two products and the price or time differentiation that the firm offers the market. For instance, firms that face increasing capacity costs should prefer a time-based strategy over a price-based strategy due to the increased demand that can result from fast delivery coupled with the price premium that can be charged for it.

Among the research that addresses dynamic pricing as a tool to improve capacity utilization, Swann (2001) investigates the joint setting of prices and production quantities when one or the other or both must be committed to at the beginning of the planning horizon. Chan et al. (2002) study the benefits of using price to influence demand levels when demand is seasonal and production is constrained so as to ensure inventory availability for periods of high demand. In a similar vein, Olsen (2003) examines optimal policies for quotation of prices and lead times dynamically as capacity "slots" become filled. Hall et al. (2003b) study the extent to which a firm can benefit from knowing the status of a production facility when making pricing decisions. In particular, they study the relationship between pricing-policy performance and the complexity of the pricing policy, measured by the amount of information required from the factory floor. The gains from using factory information can be quite high — up to a 65% increase in profit; and a fairly simple heuristic policy achieves most of these benefits. Cattani et al. (2002) study pricing decisions when a blend of make-to-order and make-to-stock production is carried out at a single facility. The analysis is designed to determine when a firm should engage in both types of production in a single facility, but there is value derived from making this decision in concert with the pricing decision.

Examples of management practice where pricing and lead time or capacity decisions are explicitly linked are few. Our conversations with managers suggest that many are pursuing more rigorous and sophisticated pricing and operations decisions, but they are doing so on parallel tracks. One exception is Tickets.com Inc., which has improved revenue per event by 45% by modifying price on the basis of supply and demand (Marshall, 2001).

Operations: Pricing and Inventory

Research on inventory management dates back to at least 1913 (Harris 1913) and perhaps even to 1888 (Edgeworth 1888), so it is not surprising that the operations community has taken steps to link inventory and pricing decisions. In fact, research on the integration of pricing and inventory was pursued almost half a century ago by Whitin (1955). That paper incorporated pricing decisions into two classic inventory-ordering models: the economic order quantity model and the newsvendor model. More generally, linking prices to inventory levels may result in dynamic pricing policies.

Two primary functions of inventory are to take advantage of economies of scale in ordering or production, leading to "cycle stocks," and to protect against uncertain-
ties in demand or replenishment times, leading to “safety stocks.”

Among salient research on cycle stocks, Blattberg et al. (1981) investigate why retailers promote, presenting evidence that promotions transfer the inventory-holding cost to consumers when both parties act to minimize their own costs. Hall et al. (2003a) study dynamic pricing and inventory-ordering decisions in a setting where manufacturers offer trade deals (discounts) to retailers and retailers manage a category of substitutable products rather than managing individual brands independently. They conclude that managing pricing and ordering for an entire category of products instead of on a product-by-product basis can create benefits that range from 15% to 50%.

While cycle-stock models generally assume that demand is known with certainty, safety-stock models allow for demand and sometimes lead time uncertainty. Safety-stock models may or may not incorporate the impact of order or production setup costs. In the absence of setup costs, safety-stock models generally lead to a “base stock” policy in which one replenishes inventory in each period to a constant level. In the presence of setup costs, it is generally only optimal to place an order when inventory has fallen below a certain reorder point.

In this regard, Federgruen and Heching (1999) studied a firm that must repeatedly decide how much inventory to have and what price to set in the absence of order setup costs. They term the optimal policy a “base-stock, list-price policy.” When the inventory level drops below a base-stock level, the firm should charge the list price and order up to the base-stock level for that period. When inventory is above the base-stock level, the firm should order nothing and charge less than the list price, in effect a type of markdown policy. However, in the absence of extraordinary increases in inventory, a single price is employed. The work of Zhu and Thonemann (2003) extends this analysis to two products with interrelated demand. For cases where demand is stable over time, the authors find

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**Referenced Research**


Feng, Y., and F.Y. Chen, Joint Pricing and Inventory Control With Setup Costs and Demand Uncertainty, working paper, Department of Systems Engineering and Engineering Management, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, Oct. 30, 2003.


that dynamic pricing has minimal impact on profit. However, when demand is non-stationary, they find that dynamic pricing can increase profits by up to 49%.

Several papers have expanded on the work of Federgruen and Heching by incorporating ordering or production setup costs. Findings differ, depending on how they model consumer demand. Feng and Chen (2003) study a case where only two prices are allowed. They find that it is optimal to employ a high price under very low and very high inventory levels and a low price under intermediate levels. Chen and Simchi-Levi (2002a, 2002b) explore the optimality of more general pricing policies under different models of consumer demand.

Software developers have taken some significant steps to integrate pricing and inventory management. Few providers, however, offer real joint optimization of pricing with inventory or other supply chain dynamics.

**Conclusion**

There is much work yet to be done to capture a full understanding of dynamic pricing, along with a sophisticated grasp of operations and the supply chain. Marketing faculty and managers need to recognize that a unit cost is not a given number, nor is a lead time a given value. Rather, their decisions to adjust price can have a dramatic effect on the supply chain and hence on profitability. Operations faculty and managers, for their part, need to appreciate the many reasons for and benefits of dynamic pricing and be willing to explore the interactions among dynamic pricing and inventory, production planning and capacity management decisions. The good news is that managers recognize the possibilities of this integration, researchers are actively pursuing increasingly more sophisticated models and implementable approaches, and software developers are building the best insights into their existing offerings.

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Zhu, K., and U.W. Thonemann, "Coordination of Pricing and Inventory Control Across Products," working paper, University of Science and Technology Hong Kong and University of Münster, 2002.