Smart Pricing:

Linking Pricing Decisions with Operational Insights

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1. Introduction

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 (ESLS), which open the door to remarkable possibilities for dynamic pricing in bricks 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, both their own internal operations and their relationships with supply chain partners. Internally, many companies have implemented the tools and concepts of lean manufacturing. And externally, they have aggressively pursued supply chain initiatives, such as eProcurement, Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting, and Replenishment (CPFR). The potential for cost reduction and service improvement is huge.

Yet, in spite of these potential benefits there is a persistent dilemma. Pricing decisions have a direct, and sometimes dramatic effect, on operations; and vice versa. This is most vividly illustrated by the well-known *bullwhip effect*, which can be initiated by price promotions. See the classic paper of Lee, Padmanabhan, & Whang (1997). Furthermore, in a recent paper, Macé & Neslin (2003) provide new insight into stockpiling (the propensity of consumers to build up inventories in response to a promotion), and deceleration (their willingness to reduce inventories in anticipation of a promotion). Figure 1, from Macé & Neslin (2003), illustrates the average estimated stockpiling and deceleration effects, for a 20% promotional price cut in week *t*. This information will be invaluable for taking pricing and promotion decisions, but one can easily see how promotions can induce the bullwhip effect, depicted in Figure 2. This insight has led many in the operations field to suggest that firms should eliminate promotions in favor of 'every day low pricing' (EDLP) – to the disdain of our marketing colleagues. Interestingly enough, the operations community has recently identified drivers for dynamic pricing in its own domain, inspired by the widely acclaimed successes of revenue management in the airline industry, where, according to one manager, "Revenue management is all of our profit, and more." (McCartney (2000)) All of these developments call for a thorough integration of marketing and operations insights – which today still appears to be lacking.

From our conversations with numerous managers we conclude that this integration is not more complete in industry than it is in academia. We have found that the most *common* practice is complete isolation of marketing from operations. The *best* practices, as far as we can tell, in spite of advanced technologies in both marketing and operations, is a regular Sales & Operations Planning (S&OP) meeting that (cordially) hashes out production and sales targets.

The perceived need for coordinating marketing and operations aspects of pricing decisions is also illustrated by developments in the software sector. Reuters (2003) reports on Manugistics (www.Manugistics.com) combining its sophisticated supply chain management (SCM) applications with its pricing and revenue optimization (PRO) applications. Manugistics describes the linkage between SCM and PRO, which they call Enterprise Profit Optimization (EPO), as the fastest growing part of their business, although Reuters reports that companies outside of the travel and hospitality industries are reluctant to pursue real EPO at this time.

This article reviews the linkage between pricing and operations. In particular, it highlights different drivers for dynamic pricing strategies. We do not aim to provide a comprehensive literature review here. Instead, we view this article as a brief snapshot into a rich and evolving field, of which we illustrate different angles with a few key references and related software initiatives. For a more extensive discussion of the literature, including technical aspects, we refer the interested reader to the excellent reviews of Rao (1993), Radjou, Orlov, & Herbert (2003), Chan, Shen, Simchi-Levi, & Swann (2003), and Elmaghraby & Keskinocak (2003)..

This article is organized around different possible drivers for dynamic pricing.. We begin with revenue management and proceed to retail markdowns. We then discuss promotions and other marketing-related drivers. Finally, we look in slightly more detail at operations-driven pricing strategies – pricing decisions made jointly with lead-time or capacity decisions, pricing/inventory decisions, and pricing/supply chain coordination.

2. Revenue Management

Revenue management (or yield management) is by far the most mature area in dynamic pricing. It is concerned with pricing a perishable resource 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 most 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 small.

Research progress in revenue management has been impressive. McGill & Ryzin (1999) provide a review of the literature as well as directions for future research, and Boyd & 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 profit of Ford (Welch (2003)). Major software providers include SABRE (www.sabreairlinesolutions.com) and Manugistics (www.Manugistics.com). Secomandi, Abbott, Atan, & Boyd (2002) describe PROS Revenue Management, Inc.'s (www.prosrevenuemanagement.com) use of revenue management tools in three nontraditional industries – pricing of advertising time in the broadcast industry, contract design in the health care industry, and capacity auctions in the natural gas pipeline industry.

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

A seminal reference for this research area is Gallego & Ryzin (1994) who investigate 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 investigate.

Another reference of practical interest on the markdown problem is Smith & Achabal (1998). Their model, which was tested and implemented at three retailers, sets prices optimally in conjunction with inventory policies, and it takes into account the impact of reduced assortment, price, and seasonal changes on sales rates. Implementation at the retailers was complex because of soft input data, existing management practices and related difficulties; and results, frankly, 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. The analysis is also used in the software developed by ProfitLogic (www.ProfitLogic.com), which includes a “Markdown Manager” module called Pricing4Profit™. More recently, markdown analyses have been extended to multiple supply chain stages (Jorgensen & Kort (2002)).

Software developments concerning markdowns are much more recent than in revenue management. Examples include 4R Systems (www.4Rsystems.com), which includes forecasting, inventory ordering and markdowns; Markdown Management Inc. (www.markdown-management.com) with solution “B_Line” that optimizes markdowns as well as initial inventory decisions; and *i2* (www.i2.com). Marshall (2001) reports that retailers have experienced improvements in gross margins of 5% – 20% from implementing markdown optimization software, so we expect to see a rapid expansion of these implementations.

4. Promotions and Dynamic Pricing from the Marketing Perspective

Promotions are commonly used for new product introductions, but they are also frequently used with staple consumer goods – tuna, soda, paper towels, and so on. 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 information about current prices, or their willingness to stockpile, then periodic promotions may allow a firm to profitably price discriminate between these different types. Price discrimination isn’t the only motivation for price promotions: promotions that are loss leaders can drive store traffic. A key academic reference on promotions is Neslin (2002). This excellent book gives a full understand of the reasons for promotions as well as an extensive review of the marketing literature in this area. However, several recent papers merit further comment.

Kannan & 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, consumer price expectations, all of which are largely ignored in the operations literature. Kopalle, Mela, & Marsh (1999) employ both descriptive and normative models to conclude that higher-share brands tend to overpromote, while lower-share brands do not promote frequently enough. They project profitability increases of 7% to 31% if their insights are employed. And as noted in the introduction, Macé & Neslin (2003) 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 consumer *consumption* and promotions. Our own research (Fleischmann, Hall, & Pyke (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 consumption curve reflects the belief that consumers use more product when they have more available, which seemed like a strong justification for promotions. However, we find that it is often optimal *not* to promote in this circumstance. We do find, however, some cases when periodic promotions are optimal, particularly when fairly strong consumption effects prevail.

These papers are representative of the marketing literature in the sense that they focus on consumer behavior and ignore operations costs and supply chain dynamics.

A number of papers have begun to expand upon the consumer behavior aspects of promotion to include upstream supply considerations. Sogomonian & Tang (1993) study the coordination of promotion and production decisions and detail the increase in profit and decrease in inventory that result. Iyer & Ye (2000)Iyer & Ye (2000) study a three-level supply chain composed of retail customers, a retailer and a manufacturer, and develop several interesting insights into promotions. For instance, if the uncertainty of the sales impact of promotions is high, it is possible that it is more profitable for the retailer not to promote at all. The most interesting result from the perspective of integrating operations and marketing decisions is that as customers' inventory holding cost decreases, their stockpiling increases, which in turn suggests that retailers will promote less frequently. Less frequent promotions mean that stockpilers purchase higher quantities 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, Iyer, & Freiheit (2002) model a case where customers react to retail promotions by stockpiling and by switching package sizes. This research incorporates 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 to promotions 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 very simple rules when making pricing and promotion decisions, although there are some notable exceptions. Software solutions are beginning to provide the tools that can help managers add a level of science to the art of pricing. These include, for example, Manugistics *Profitable Promotions Management* (www.Manugistics.com), which predicts the jump in sales due to promotions, and KhiMetrics (www.khimetrics.com), which has a promotion manager that measures and optimizes the effect of promotions on sales.

5. Operations: Pricing Decisions in Conjunction with Lead Time or Capacity Decisions

In this section we focus on research that has integrated pricing issues with management of lead time and production capacity. This research can be divided into a segment that integrates pricing concerns into the capacity procurement decision, which reflects a long time horizon, and a segment that is focused on a shorter time horizon: using pricing to make the best possible use out of the available capacity, akin to revenue management.

Three recent papers that model the long-term capacity choice are So & Song (1998), Van Mieghem & Dada (1999) and Boyaci & Ray (2003). So & 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 & Dada (1999) illustrate how competition, uncertainty, and the timing of operational decisions influence capacity investment. Boyaci & 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 to the market. For instance, firms that face tight capacity constraints should prefer a time-based strategy to a price-based strategy.

Among the research that addresses dynamic pricing as a tool to improve capacity utilization, is the Ph.D. dissertation by Swann (2001). This work 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, Simchi-Levi, & Swann (2002) study the benefits of using price to influence demand levels when demand is seasonal and production is constrained so as to insure 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, Kopalle, & Pyke (2003) 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 utilizing factory information can be quite high – up to 65% profit increase; and a fairly simple heuristic policy achieves most of these benefits. Cattani, Dahan, & Schmidt (2002) study pricing decisions when a blend of make-to-order and make-to-stock production is carried out in a single facility. The analysis is designed to determine when a firm should engage in both types of production in a single facility, but one lesson is the value 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 which has improved revenue per event by 45% by modifying price based on supply and demand (Marshall (2001)).

Software tools appropriate to this area are covered at the end of Section 6, but one solution provider, Revenue Technologies (www.revenuetech.com), merits a note specifically in this section because their software helps automate the entire process of negotiating and managing contract pricing.

6. Operations: Pricing Decisions in Conjunction with Inventory Decisions

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 in Whitin (1955). That paper incorporated pricing decisions into two classic inventory-ordering models, the Economic Order Quantity model and the newsvendor model.

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 uncertainties in demand or replenishment times, leading to "safety stocks." We begin this section with research that focuses on cycle stocks.

Blattberg (1981) investigates *why* retailers promote. This paper presents evidence that promotions serve to transfer inventory holding cost to consumers when both parties act to minimize their own costs. Hall, Kopalle, & Krishna (2003) study dynamic pricing and inventory-ordering decisions in a setting where manufacturers offer trade deals (discounts) to retailers, and retailers manage of a category of substitute products (e.g., frozen orange juice). They detail the benefits to the retailer of managing pricing and ordering for the entire category of products instead of on a product-by-product basis. They conclude that these benefits can range from 15% to 50%.

Cycle stock models generally assume that demand is known with certainty. Safety stock models, on the other hand, 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 it is optimal to begin every inventory cycle with a "base stock" of the product by placing an appropriately sized order. In the presence of setup costs, it is generally only optimal to place an order when inventory has fallen below a certain reorder point.

An important paper in this stream is Federgruen & Heching (1999) who study a firm that must repeatedly decide how much inventory to have on hand 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, order nothing and charge less than the list price, in effect a type of markdown policy employed under high inventory levels. However, in the absence of extraordinary increases in inventory, a single price is employed.

The work of Zhu & Thonemann (2003) is similar to Federgruen & Heching (1999), but includes two products with interrelated demand. For cases where demand is stable over time, the authors find that dynamic pricing has minimal impact on profit. However, when demand is nonstationary, they find that dynamic pricing can increase profits by up to 49%.

A number of papers have expanded on the work of Federgruen & Heching (1999) by incorporating ordering or production setup costs. The results of these papers differ depending on how they model consumer demand. Feng & Chen (2002) 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 & Simchi-Levi

(2002a) and Chen & Simchi-Levi (2002b) explore the optimality of more general pricing policies under different models of consumer demand. The exact policies differ from Federgruen & Heching (1999) and Feng & Chen (2002), but the fundamental forms are quite similar.

Software developers have taken some significant steps to integrate pricing and inventory management. Rapt (www.rapt.com) has a procurement module that models the tradeoff of too much versus too little inventory, and a price module that sets prices based on a price-demand curve. It also allows prices to change based on inventory levels. DemandTec (www.DemandTec.com) likewise employs the price-demand curve, but this software also captures substitution effects within a category, as well as some rudimentary cost measures. For instance, DemandTec quantifies the cost of loading and unloading in the warehouse, which depends on whether the item is large or small, packed on pallets or not, and so on. KhiMetrics (www.KhiMetrics.com) also provides tools for category management/substitution effects, the price-demand curve, competitor prices, promotions, and other constraints. Few software providers, however, offer real joint optimization of pricing with inventory or other supply chain dynamics. One apparent exception is Retek (www.Retek.com), which claims to integrate forecasting, inventory replenishment and pricing and promotion. Our perception, however, is that it is quite weak in terms of further supply chain dynamics. And as noted above, sales of Manugistics' Enterprise Profit Optimization (EPO) are growing very fast

7. Conclusion

We hope it is clear from this review that the academic literature on joint pricing/operations decisions has made significant strides. In some areas, like revenue management and retail markdowns, software and management implementation of the models and insights has been truly impressive. In other areas, like pricing/capacity or pricing/inventory, the academic progress has been primarily theoretical and practical implementation remains elusive. There is much work 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 (see Figure 3 for example), 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 between 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 more and more sophisticated models and implementable heuristics, and software developers are building the best insights into their existing offerings.

Suggested Reading

Cross (1997) for revenue management

Wilson (1993) for pricing

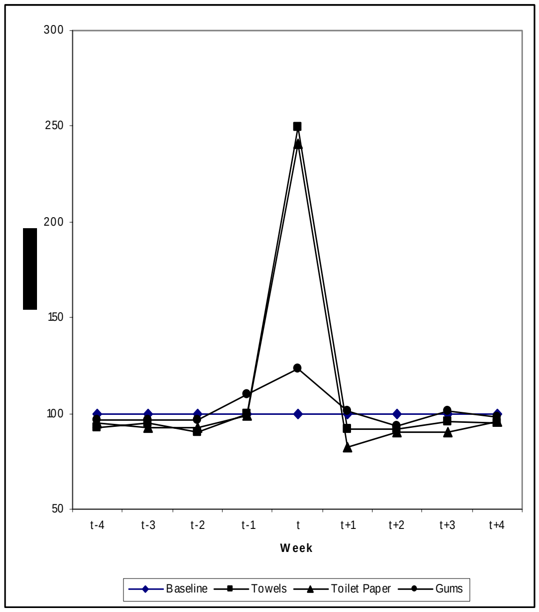

Figure 1: Stockpiling and Deceleration (reprinted from Macé & Neslin (2003))

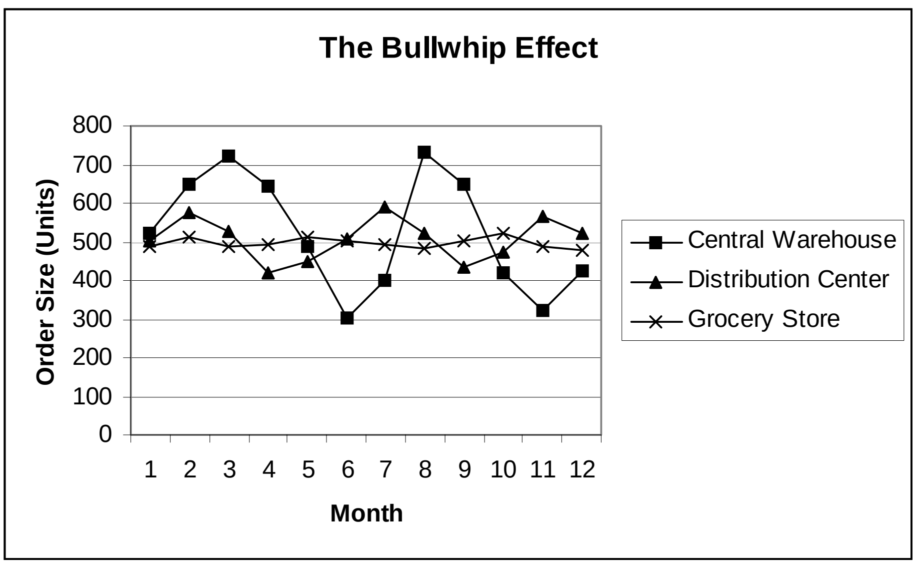

Figure 2. An Illustration of the Bullwhip Effect

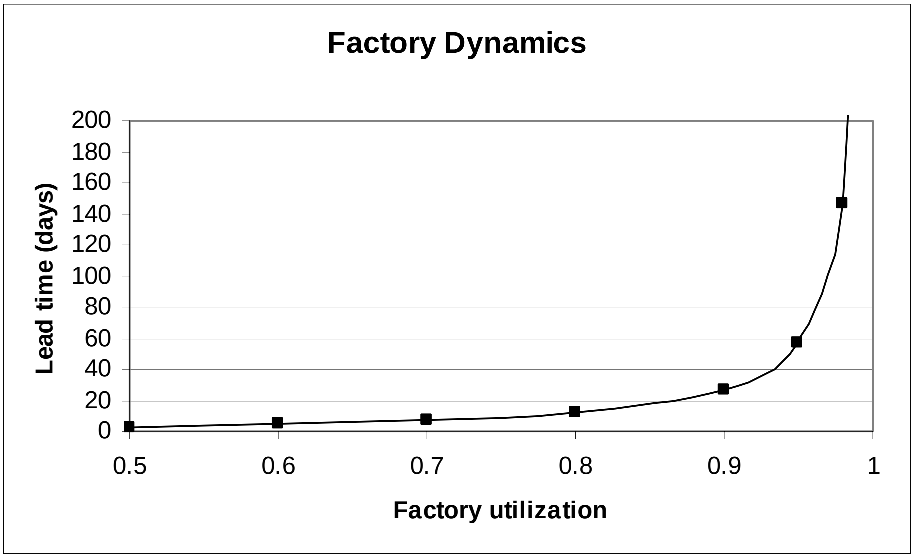

Figure 3. The Effect of Increased Utilization on Lead Time

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