

Dynamic Pricing in the Presence of Inventory Considerations: Research Overview, Current Practices and Future Directions¹

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Abstract

The benefits of dynamic pricing methods have long been known in industries, such as airlines, hotels and electric utilities, where the capacity is fixed in the short-term and perishable. In recent years, there has been an increasing adoption of dynamic pricing policies in retail and other industries as well, where the sellers have the ability to store inventory. Three factors contributed to this phenomenon: the increased availability of demand data, the ease of changing prices due to new technologies, and the availability of decision-support tools for analyzing demand data and for dynamic pricing. This paper constitutes a review of the literature and current practices in dynamic pricing. Given its applicability in most markets and its increasing adoption in practice, our focus is on dynamic (intertemporal) pricing in the presence of inventory considerations.

(Dynamic Pricing; E-commerce; Revenue Management; Inventory)

1 Introduction

In recent years, we have witnessed an increased adoption of existing dynamic pricing strategies and their further development in retail and other industries [18]. Three factors contributed to this phenomenon: the increased availability of demand data, the ease of changing prices due to new technologies, and the availability of decision-support tools for analyzing demand data and for dynamic pricing. Determining the “right” price to charge a customer for a product is a complex task, requiring that a company know not only its own operating costs and availability of supply but also how much the current customer values the product and what future demand will be. Therefore, in order to charge a customer the right price, a company must have a wealth of information about its customer base and be able to set and adjust its prices at minimal cost. Until very recently, neither element was present; companies had limited ability to track information about their customers’ tastes, and faced high costs in changing prices. Today, in both Internet and brick-and-mortar stores, new

¹Pinar Keskinocak is supported by NSF Career Award DMI-0093844. This research is also supported in part by a grant from The Logistics Institute Asia Pacific (TLI-AP). We would like to express our deep gratitude to the editors Art Geoffrion and R. Krishnan, and an anonymous referee, for their tireless efforts in improving this paper. We would also like to thank David Barach, Phil Delurgio, Aliza Heching, Itir Karaesmen, Murali Mantrala, Srinivas Palamarthy, Linda Whitaker, and Loren Williams for their helpful feedback on previous versions of this paper.

technology allows retailers to collect information not only about the sales, but also about demographic data and customer preferences. Due to the ease of making price changes on the Internet, dynamic pricing strategies, especially in the form of price markdowns, are now frequently used in B2C as well as B2B commerce by numerous companies, including FairMarket, Comp USA, Lands' End, J.C. Penney, MSN Auction and Grainger. Although price changes are still costly in traditional retail stores, this may soon change with the introduction of new technologies such as Electronic Shelf Labeling Systems [69]. These advances in technology have opened the door for dynamic pricing optimization solutions providers (DPOSP), who offer decision-support tools for sophisticated pricing strategies utilizing a blend of complex optimization methods. Even with limited ability to change prices today, early users of the new pricing decision-support software have reported improved financial performance, quick return on investment, and no negative impact on price image. AMR Research predicts that the market for pricing optimization tools should grow from about \$75M in 2002 to at least \$500M by 2005 [30].

While the types of pricing policies/methods used in the exchange of goods and services vary greatly, they fall into two broad categories: *posted price* mechanisms and *price discovery* mechanisms. Under a posted price mechanism, a good is sold at a take-it-or-leave-it price determined by the seller. In price discovery mechanisms, prices are determined via a bidding process, such as auctions. Our focus in this paper is on dynamic posted price mechanisms (we refer the reader to [42] and [50] for a comprehensive review of the auction literature).

In the past, companies would fix the price of a product or service over a relatively long time period, i.e., the posted prices were usually *static*. This was mainly due to the absence of accurate demand information, the high transaction costs associated with changing prices and the huge investments required for software and hardware necessary for implementing a dynamic pricing strategy. *Dynamic* posted prices are also take-it-or-leave-it prices, where the seller changes prices dynamically over time (intertemporal prices), based on factors such as the time of sale, demand information, and supply availability. With the goal of balancing demand and supply, early applications of dynamic pricing methods have been mainly in industries where the short term capacity (supply) is difficult to change, such as airlines, cruise ships, hotels, electric utilities, sporting events, and health care [28] [29] [51] [81]². In most of these industries it was possible to control prices in a centralized fashion and prices could be changed at little or no cost. In contrast, in industries such as retail where short term supply is more flexible (e.g., through inventory replenishment) or where price changes

²Dynamic pricing practices in these industries are known as yield management (or revenue management, or perishable asset revenue management). The key factor behind revenue management is the segmentation of the market into multiple classes (e.g., business vs. leisure customers), where different types of 'products' (e.g., fully refundable fares vs. restricted fares that require Saturday night stays) are targeted to each class (second degree price discrimination). The main focus in revenue management research has been on the allocation of limited capacity to different demand classes. For example, in the airline industry, given a booking request that asks for seats in an itinerary in a specific booking class, the fundamental revenue management decision is whether to accept or reject this booking, i.e., overbooking and seat inventory control [51]. In this domain, most of the literature on pricing decisions focuses on industry-level trends and implications, rather than operational level decisions. Recent papers that discuss revenue management research and practices include [3] [41] [51] [81].

are costly, the focus has been on improving inventory management practices. Advances in information technology and e-commerce have played a significant role in improved inventory management. For example, programs such as CPFR (collaborative planning, forecasting and replenishment), QR (quick response) and VMI (Vendor Managed Inventory) enable information sharing and collaboration among supply chain partners, lowering inventory costs while simultaneously increasing service levels. However, despite significant improvements in reducing supply chain costs via improved inventory management, a large portion of retailers still lose millions of dollars annually due to lost-sales and excess inventory. Therefore, many are now willing to look at the demand side of the supply-demand equation, re-examine their pricing policies and explore dynamic pricing software technologies for better demand management.

This paper constitutes a review of current practices in dynamic pricing as well as the dynamic pricing literature. To better understand the state-of-the-art pricing practices, we conducted interviews with the Directors of Marketing and Operations of leading DPOSPs in the field, including DemandTec, Khimetrics, ProfitLogic and Spotlight Solutions. We also spoke with Manugistics, i2 and Retek, leaders in supply-chain management and ERP software, who are moving into price optimization solutions. Based on our discussions with DPOSPs and the dynamic pricing literature from the fields of operations research, economics and marketing, we suggest a categorization of market environments for which distinct dynamic pricing problems arise (Section 2). We then discuss the price optimization solutions currently offered by DPOSPs, the challenges they face in their implementation, provide an overview of the existing relevant literature, and propose future directions for research (Sections 3 and 4). While most of the literature reviewed here is motivated by a physical retail or purchasing environment, the results and insights are applicable both to brick-and-mortar and online selling environments. There are, however, some unique characteristics of the online selling environment, which offer additional flexibilities and challenges in pricing decisions. We conclude by discussing the impact of these unique characteristics of online stores on pricing decisions and additional research directions in Section 5.

Given its applicability in most markets and its increasing adoption in practice, our focus in this survey is on dynamic (intertemporal) pricing in the presence of inventory considerations. A short list of references and discussion on other branches of the pricing literature not reviewed here can be found in the online Appendix. Our survey complements other surveys of the pricing literature from the operations research/management science community that focus on revenue management for fixed, perishable capacity [6] [51], and coordinated pricing and production/procurement decisions [12] [82], from the marketing community that focus on how markets behave [55], goods with dependent demands (Bass models) [62] [63] [54] and brand loyalty and switching [26], and finally from the economics community that focus on price discrimination [73] [76]. We complement these surveys by focusing on dynamic pricing in the presence of inventory considerations, providing a critical analysis of the current practices in dynamic pricing, highlighting the potential for dynamic pricing in ecommerce, and presenting a substantial list of future research directions.