Omega 39 (2011) 528–538

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Optimal pricing and production decisions in the presence of symmetrical and asymmetrical substitution

Sang-Won Kim [a,*], Peter C. Bell [b]

[a] College of Business Administration, University of Ulsan, 102 University Road, Ulsan 680-749, Republic of Korea
[b] Richard Ivey School of Business, The University of Western Ontario, 1151 Richmond Street North, London, Ontario, Canada N6A 3K7

ARTICLE INFO

Article history:
Received 18 May 2010
Accepted 11 November 2010
Available online 18 November 2010

Keywords:
Revenue management
Pricing
Demand substitution
Production capacity decision
Symmetrical and asymmetrical demand

ABSTRACT

Firms may produce a variety of generally similar products or may practice "scientific pricing" or revenue management where the firm will offer similar or somewhat differentiated products in multiple market segments at different prices. Whenever generally similar products are available, the demand for the products is linked through the ability of the customer to substitute one product for another. One widely known type of demand substitution is referred to as inventory-driven substitution where a customer will substitute for a product that is out of stock by buying a similar product. A second type of substitution occurs as a response to price-differences when a customer substitutes a less expensive product for a similar higher priced product.

As firms use dynamic pricing to match demand with inventory or capacity while maximizing revenue or contribution, there is a need to take into account the fact that the creation of price differences between market segments will motivate customers to try to switch from higher priced segments to lower priced segments leading to price-driven product substitution. If the firms' price behavior leads to stockouts, inventory-driven product substitution may also occur. Both these effects will impact the firms' price and production capacity decisions.

In this paper, we consider the impact of price-driven substitution on a firm's pricing and production capacity decisions for a single period, when the firm sells to multiple market segments. We show that revenue managers and supply chain coordinators should adapt product prices in each market segment and order quantities to take into account substitution by customers and the costs of supplying product to each market. We develop both deterministic and stochastic models with substitution as a result of price-differences. We investigate the impact of the symmetrical and asymmetrical demand substitution on optimal prices, production levels and revenue or contribution and the impact of changes in the production cost on the optimal solutions.

1. Introduction

Revenue management pricing, sometimes called "scientific pricing" began life in the service industries in the mid 1980s and is now migrating to the pricing of manufactured goods (for a history, see [5]). This migration, however, is not seamless: in the service industries it is common to assume that the product cost is zero but this is usually an inappropriate assumption for manufactured goods. The existence of, perhaps substantial, manufacturing costs complicated the calculation of optimum prices, but the existence of significant overstocking costs also makes revenue management pricing decisions heavily dependent on the accuracy of demand estimates. For manufactured goods, demand arises from several sources. The regular, price-sensitive demand for many products can be augmented by demand that arises from the fact that the prices of substitute products have increased causing potential buyers of these products to look for less expensive alternatives. Also, there may be additional demand arising from the fact that other similar products are sold out and not available. These demand augmenting effects are termed price-driven substitution and inventory-driven substitution.

Revenue managers enhance firm revenues by segmenting a single market into multiple smaller markets and pricing to each market segment separately and optimally. The firm selling similar products in multiple market segments can use pricing and product availability decisions to move demand across segments if this improves the firm's profitability. As the revenue manager creates price differences between market segments, some customers can be expected to respond by switching segments, while if the firm decides to reduce the amount of product available in certain segments, customers can be expected to respond to the resulting

* Corresponding author. Tel.: +82 10 9960 4421.
E-mail addresses: studyksw@ulsan.ac.kr (S.-W. Kim), pbell@ivey.uwo.ca (P.C. Bell).

0305-0483/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.omega.2010.11.002

stockouts by buying the product in a different market segment rather than going without product.

We illustrate these ideas using the example of Coke and Pepsi. These are close substitutes stocked by all major supermarkets and grocery stores. Any attempt to forecast demand for Pepsi must take into account the expected price for Coke: if Coke runs a special low-price promotion, Pepsi demand will be lower than expected, perhaps much lower, as customers who normally buy Pepsi take advantage of the promotion and switch to Coke. In addition, if one or other product stocks out, the demand for the other can be expected to soar since most cola buyers will not spend the time going to another store searching for the stocked-out brand. In this example, the cola brands are owned and distributed by competing firms but the revenue manager creates a similar situation through market segmentation.

The revenue manager will offer essentially the same product via multiple market segments: for example through a retail channel, an internet channel, and a catalog sales channel. By restricting product availability in some low priced channels, the revenue manger can push some (but likely not all) unsatisfied demand to higher priced channels (inventory-driven substitution) and by creating price differences between channels some customers can be expected to switch channels (price-driven substitution). If revenues are to be maximized through joint pricing and inventory decisions across all market segments, the revenue manager will be able to improve demand forecasts and hence the performance of the pricing algorithms, by taking into account the effect of these two type of substitution on the demand for its product.

Research on the substitution effects of a price change includes Paul [26], who developed a gasoline price control model and argued that the US Environmental Protection Agency opposed gasoline price decontrol because a wider posted price differential between leaded and unleaded gasoline would induce more consumers to switch illegally to leaded gasoline. Taheri [34] investigated substitution among such fuels as coal, natural gas, and electricity during the oil price increases of the 1970s. Birge et al. [2] studied optimal price and production capacity decisions with stochastic (uniformly distributed) price-dependent demand for two substitutable products for a single period, where each product was sold in a single market. Birge et al. [2] analyzed three cases: first, capacity decisions at a given price of each product; second, pricing and capacity decisions when the price of one product and the capacity level of the other product were given; and third, pricing decisions when the capacity of each product was given.

Inventory-driven substitution has been studied using multi-product single-period inventory models with one-way substitution, e.g. [25,14,18,1,3]. Examples of single-period or multi-period stochastic inventory models with one-way inventory-driven substitution include Bassok et al. [1], Hsu and Bassok [16], Smith and Agrawal [32], Rajaram and Tang [28], Rao et al. [29], Hopp and Xu [15], Yucel et al. [38], Shumsky and Zhang [31], and Dutta and Chakraborty [9]. These authors assumed that the manufacturer or manager was a price taker for all of the products.

Revenue management uses pricing and inventory control strategies to balance supply and demand, and pricing decisions are prominent is some research on inventory management. Research on pricing with or without considering substitution includes Fedgergruen and Heching [13], Petruzzi and Dada [27], Elmaghraby and Keskinocak [11], Chen et al. [6], Li [21], Dye [10], Su [33], Tomlin and Wang [35], Dong et al. [8], Pan et al. [24], Tsai and Hung [36], and Eren and Maglaras [12]. Bodily and Weatherford [4] proposed an airline seat inventory management model with customer substitution but did not consider pricing decisions.

Although pricing and inventory control decisions are closely related, there is limited research on demand substitution that results from their interdependence. While there are a number of papers that integrate pricing and inventory level decisions, research on joint pricing and inventory decisions when substitution is considered is limited. Perhaps this is because traditionally the marketing department looks after pricing decisions while a manufacturing or purchasing department manages inventory levels. Recently, research papers on joint pricing and inventory control with substitution have appeared. Zhang and Bell [39] studied joint pricing and inventory decisions with demand leakage. They modeled demand leakage across market segments as a function of price differences (price-driven substitution), where the demand lost in one market moves perfectly to the other market. Kuyumcu and Popescu [20] studied joint pricing and inventory control by considering deterministic optimization models for multiple substitutable products and they showed that the optimization problem can be reduced to a pure pricing problem. Their research was conceptual and did not provide a detailed procedure for finding optimal solutions. Karakul and Chan [17] considered a stochastic optimization problem for joint pricing and inventory decisions when considering an existing product and a new improved product. The authors developed an in-depth mathematical procedure for finding optimal solutions for the stochastic problem with stockouts-based (inventory-driven) substitution. Kocabiykoglu and Popescu [19] considered joint pricing and inventory revenue management models with price-sensitive demand substitution, and extended the traditional two-fare class model based on EMSR.

In summary, while there are a number of optimization models with demand substitution in both the inventory and capacity management areas although most of these studies has not included pricing decisions. In addition, there are many pricing models, but most of these models do not consider inventory or production decisions with demand substitution. The motivation of the current research is to attempt to introduce demand substitution with pricing and inventory/capacity decisions into a revenue management context. Our research differs from earlier research although following Zhang and Bell [39], and we focus on demand leakage as a function of price differences. Following Kuyumcu and Popescu [20], we also consider a deterministic optimization model, however, unlike Zhang and Bell [39] and Kuyumcu and Popescu [20], we consider the impact of both symmetrical and asymmetrical demand leakage. We compare a deterministic model with its stochastic equivalent and provide a detailed analytical procedure to determine optimal solutions. In our stochastic model, unlike Karakul and Chan's [17] inventory-driven substitution model, we focus on price-driven substitution. We examine the impact of substitution on the optimal price, production quantity and total expected revenue by examining how optimal pricing and production decisions are affected by demand substitution which is driven by price differences.

2. The model

We consider a price-driven substitution model where a manufacturer or distributor offers the same or similar products in two market segments (for example, an internet channel and a retail channel where we would expect the product to have a higher price in retail channel than the internet channel). Demand substitution is realized from the market segment with the higher-priced product to the market segment with the lower-priced product. Specifically, we consider two market segments (A and B) where the unit price in market A is higher than the unit price in market B. We assume that the demand for the product in both market segments is dependent on the price set in both segments with the demand in segment A decreasing with the price set in segment A and increasing in the price set in segment B and the demand in segment B decreasing with the price set in segment B but increasing in the price set in segment A.