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"Joint pricing and inventory decisions for substitutable and perishable products: An analysis"

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Abstract:

In this paper, we create a model for making pricing and inventory decisions over multiple periods for products that can be used as substitutes and are perishable. Retailers place orders at the beginning of the first period and sell the products at full price during that time. Any leftover items are carried over to the next periods and sold at lower prices. The demand for these leftover items is based on a model that depends on how much the prices of substitutes are reduced. The best order quantities and prices are found by aiming to get the highest possible total profit over time, taking into account the money made from sales, the cost of not being able to meet demand (backorder cost), and the cost of keeping inventory (holding cost). We look at some key features of the best strategy, like how the value of decisions changes in a curved way (concavity), and use these to help find the best prices and order amounts. We also show results from a case study with a high-street fashion company, which shows the advantages of making pricing and inventory decisions together for products that can be substituted.

Keywords: *inventory control; trade credit; deterioration; pricing*

Introduction

Retailers often have many products available, and customers are usually happy with a different product if their preferred one isn't available or is too expensive. This tendency to substitute means that when making pricing and inventory decisions, it's important to think about multiple products at the same time. The prices set for a product can strongly affect how much customers want to buy, which in turn affects how much inventory should be ordered. Because of this connection, making pricing and inventory decisions at the same time is more common now than before (e. g. , Abad, 1996; Federgruen and Heching, 1999; Gilbert, 2000; Rajan, Steinberg, Steinberg, 1992; Zhu and Thonemann, 2009). For products that go bad quickly, retailers usually reduce prices over time. By making pricing and inventory strategies that span over multiple periods and account for product substitution, this helps reduce waste. We look at the situation where a retailer is selling a group of products that can be used as substitutes and where the starting prices are set according to what the supplier suggests.

The goal for the retailer is to make the most profit from selling these products, taking into account the cost of not being able to meet demand (backorder cost) and the cost of storing inventory (holding cost). The decisions we're making are about the lower prices in later periods (markdown prices) and the best amount to order at first. The demand for each product is not certain and depends on the prices of all the products in the group, which we call cross-price dependency.

There's a lot of research on joint pricing and ordering decisions. Rajan et al. (1992) studied this issue for a monopolistic retailer. In their model, prices can change over the inventory cycle and backlogging is not allowed. Abad (1996) looked at a model where a retailer sells a perishable product and can backorder some orders, finding that this strategy can help control costs for highly perishable products. Federgruen and Heching (1999) looked into strategies for setting prices and restocking when there is uncertainty about demand. They considered both short and long timeframes and thought about two ways prices can change: (i) prices can be changed in any direction, and (ii) prices can only decrease. They developed the best strategy by looking at the properties of each model. Li, Lim, and Rodrigues (2009) studied the problem of pricing and managing stock for a perishable product that has a fixed lifetime.

They treated the problem as a Markov decision process and created an optimal base-stock and list-price strategy. Rujing (2007) researched the joint pricing and inventory decisions for a single perishable product that has a multiple-period lifetime. They assumed that decision makers decide the best amount to order at the start and a pricing strategy based on the remaining inventory and time left.

This problem is related to dynamic pricing research, which has seen more attention on pricing models for multiple products since 2006, as discussed in the review by Chen and Chen (2015). Most of these models assume that customer arrivals follow a Poisson pattern. When there is no distinct preference order between products (horizontal differentiation rather than vertical differentiation), customer choices are usually based on models that randomize customer utility (e. g. , Akcay, Natarajan, Xu, 2010; Dong, Kouvelis, Tian, 2009; Li and Graves, 2012; Suh and Aydin, 2011). These models don't include inventory decisions, as they usually assume that inventory is fixed in advance. Because they are mainly used for selling transport and leisure services, they don't include holding or backorder costs.

Despite the extensive literature in this area, to the best of our knowledge, this is the first work considering the joint pricing and inventory control problem across substitutable and perishable products over multiple periods taking account of holding and backorder costs. Gilbert (2000) studies a joint pricing and production schedule problem for a set of items but where a single price is used for the entire planning horizon. Demand is assumed to be seasonal and price dependent but cross-price effects on demand are not considered. A retailer faces cross-price effects when the demand for each product depends on the prices of other products in the market. Zhu and Thonemann (2009) do incorporate cross-price effects in their study, considering a joint pricing and inventory control periodic review problem for a retailer across two similar products. They derive the optimum joint pricing and inventory policy and find that the retailer can significantly improve profits by managing the two products jointly as opposed to independently, particularly under high cross-price demand elasticity. They also find that the retailer can improve profits by using dynamic pricing when demand is non-stationary. In both of these examples, the products are assumed to be non-perishable and consequently policies do not need to consider the shelf-life of products. Smith and Agrawal (2000) ignore the effect of price but use a newsboy formulation to develop optimal inventory policies that account for substitution effects. This joint selection of stock levels for substitutable products is shown to have a significant impact on the optimal inventory policies and profit margins.

The key contributions of our work are:

- We develop a stochastic dynamic programming model to study the joint pricing and inventory decision problem for substitutable and perishable products with stochastic demand. The model is introduced in Section 2.
- We derive analytical properties of the optimal decisions in Section 3.1. We show that the value functions are concave under mild conditions, which allows us to develop an efficient numerical scheme for finding the optimal joint ordering and pricing policy in Section 3.3. It should be noted that, while the concavity property has been shown previously in the inventory control literature, we show that the proof techniques in some of the existing work need to be more rigorous. Existing

work has also generated these results in models that do not involve all the complexities of substitutability, perishability, multi-periods, and multiple products that we do. We provide a discussion of this in Section 3.2.

- The numerical results are based on a case study with real data, and are presented in Section 4, where we demonstrate the benefits of the strategies proposed.

Model formulation

We consider a setting in which decision makers, e.g., retailers, make pricing and ordering decisions over substitutable products at the beginning of the first period and pricing decisions during the subsequent discount periods. Here, the selling season is split into distinct time periods, where the prices on offer are constant during each period. Retailers are unlikely to want the duration of the markdown period to be equal to the time that the product is on sale at full price. As a result, the

Finding the optimal pricing and inventory policy

In this section, we first derive some theoretical properties on the concavity of the profit-to-go functions. We also discuss some common mistakes in the literature when deriving this for similar multi-period joint inventory and pricing problems. Finally, we use the concavity property to develop a numerical scheme for finding the optimal pricing and inventory policy.

Numerical results

In this section, we demonstrate how a retailer can improve profitability by making the pricing and inventory decisions together. This is demonstrated through 110 randomly generated instances and through a case study of a joint pricing and inventory problem, considering substitution between two similar products. The case we worked on is the sale of a new design of jeans in the winter collection (2015–2016). We collect data from the sales of the old design with two different washes (stone washed

Conclusion

In this paper, we develop a stochastic dynamic programming model for joint pricing and ordering decisions over substitutable products. The framework is applicable to settings where there are multiple discounting periods and where the values of perishable products decrease quickly such as in fast fashion industries. Once the ordering decision is made at the beginning of the first period, no replenishment is considered but discounted retail prices might be offered in the subsequent periods. We

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