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A risk tolerance analysis for a joint price differentiation and inventory decisions problem with demand leakage effect

Syed Asif Raza[a,*], Sivakumar Rathinam[b]

[a] Qatar University, Doha, Qatar
[b] Texas A & M University, College Station, USA

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ABSTRACT

Price differentiation is a commonly used practice in Revenue Management (RM) to improve a firm's profitability. However, most studies in the literature have considered a risk-neutral firm to demonstrate the benefits of price differentiation. The main contribution of this paper is in considering several important objectives while determining the optimal product prices and order (production) quantities for a risk-adjusted firm with demand leakage effects in the presence of a price-dependent stochastic demand. The objectives considered include the maximization of a firm's expected profit and maximizing the probability of exceeding the risk adjusted expected revenue. Closed-form expressions for optimal product prices and production quantities are derived for several of these objectives. A numerical study is also presented to calibrate the impact of a firm's risk tolerance and other factors such as demand leakage, market demand variability on the firm's profitability and its optimal decision.

1. Introduction

The benefits of price differentiation are well established as a promising tool in Revenue Management (RM). RM provides a set of strategies and tactics that are geared towards augmenting the profitability of a firm. Using price differentiation, a seller offers the same or slightly different products in a market at distinct prices. The firms also often use price differentiation when they offer their products using segregated distribution channels. Zhang and Bell (2012) have documented numerous examples and a taxonomy about how the price differentiation is utilized in many real life applications. However, the benefits of price differentiation in these studies assumes perfect fencing while demand leakage (also referred to as *cannibalization*) occurs commonly in practice. Perfect fencing may not be possible due to heterogeneity among customers and the market structure. Recent studies have explored the effect of cannibalization for risk neutral firms in Zhang et al. (2010), Raza (2015a), and Raza (2015b). This article generalizes these studies for risk-averse firms where multiple objectives are at play simultaneously.

The objectives we consider naturally arise in a revenue management problem and are quantities of significant interest to a risk averse firm. One of the critical objectives any firm must consider is the maximization of its expected profit. Maximizing the expected profit is non-trivial as the difficulty of solving this problem depends on the extent to which the demand distribution is known to the firm. There are at least three possibilities here: the demand distribution is known completely; the demand distribution is unknown; the demand distribution is unknown but some bounds on the demand are known. The expected profit is maximized considering each of these three possibilities in this article. Next, any risk averse firm would be interested in maximizing the probability of exceeding the risk adjusted expected revenue (this is also referred to as maximizing the satisficing level). There may also be scenarios where a firm may have to consider both maximizing its expected revenue and the satisficing level simultaneously. The key contribution of this article lies in addressing each of the objectives for a firm where a demand leakage can occur between its market segments. Both the optimal product prices and production quantities are identified systematically and simulation results are presented to corroborate the proposed approach. In the remainder of this section, an extensive review of the literature is presented and a summary of all the objectives considered is outlined further.

1.1. Literature review

This study interfaces the following relevant areas:

1.1.1. Newsvendor problem (NVP) framework and risk consideration

The NVP is one of the fundamental and widely used frameworks for

* Corresponding author.
E-mail addresses: syedar@qu.edu.qa, sasif.raza@gmail.com (S.A. Raza), srathinam@tamu.edu (S. Rathinam).

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formulating revenue management problems as noted in McGill (1995). NVP traces back its history to the work in Edgeworth (1888), and since then, it is perhaps the most adopted framework for a verity of RM problems. RM has a rich history of over 4 decades of applications primarily in service sector like airline, hotels, restaurants, resorts, amongst others (Philips, 2005; Talluri and Ryzin, 2004). However, the application of RM in manufacturing is relatively recent and often significantly different from that of an service industry (Boyd, 2007). In a standard NVP setting, the objective of the firm (newsvendor) in revenue management is to maximize the total expected revenue (or the expected profit) in a single selling period. The firm offers the product at a fixed (exogenous) price, and it exercises a control over the order quantity so as to maximize the total expected profit. A very natural extension to standard NVP is to consider endogenous (variable) prices in a stochastic setting. Thus, in a NVP with pricing, the price of a product is also a decision along with the order quantity (inventory). The NVP with pricing also has a history of more than 50 years. Whitin (1955) was the first to discuss the pricing issues in the inventory control theory. Mills (1959) extended the work reported in Whitin (1955) by modeling the uncertainty of the price sensitive demand. He suggested an *additive* modeling approach. Later, Karlin and Carr (1962) presented a *multiplicative* modeling approach to the problem. Historically, both additive and multiplicative models became vital in pricing research with stochastic inventory control (see (Khouja, 1999), (Petruzzi and Dada, 1999), and (Yao et al., 2006) for more details). In recent years, there is still a growing interest in addressing the optimal pricing problem in the NVP framework. Recently various extensions to the NVP which also consider pricing decisions have been addressed. The full coverage of all such extensions is out of the scope of this paper, but the reader may refer to some recent papers; Sun et al. (2013), Kwon and Cheong (2014), Wu et al. (2013b), Guo and Ma (2014), Moritz et al. (2013), Yu et al. (2013), Lee and Jung, 2014, Abad (2014), Kwon and Cheong (2014), Wang et al. (2015), Zhu (2015), Li et al. (2016), Khouja (2016), etc.

The consideration of the risk-aversion or adjustment has also attracted the focus of researchers within the NVP community as well as in the RM context. In Eeckhoudt et al. (1995), authors discuss the risk-averse NVP with exogenous pricing. However, only recently Chen et al. (2009a) studied the NVP with pricing under the Conditional Values at Risk (CVaR) criterion. Wu et al. (2013a) explored NVP with random shortage cost under a risk criterion; later Wu et al. (2013b) also studied the same problem with random capacity. Some other developments with the mean-variance criteria can also be seen in Dai and Meng (2015), Wu et al. (2014), Xinsheng et al. (2015), and Rubio-Herrero et al. (2015). Luo et al. (2015) considered limited capacity and outsourcing with the CVaR criterion. Xu et al. (2016) investigated NVP model with the CVaR of opportunity loss. Xu et al. (2016) considered loss-averse NVP with supply options.

1.1.2. Price differentiation and market segmentation

RM offers several tools for augmenting profitability, and among these, *price differentiation* is commonly used. Price differentiation refers to the practice in which a seller offers different price to distinct customers while selling the same product (or service) or a slightly different version of the same product (Philips, 2005; Talluri and Ryzin, 2004). One can refer to Zhang and Bell (2012), and Zhang et al. (2010) for several examples from real life. The price differentiation is implemented using a distribution channel, point of sale, or a sale restriction, etc. In practice, however, in markets where customers are more heterogeneous in their willingness to pay (WTP), demand leakages can occur between segments (Zhang et al., 2010; Raza, 2015b), (Fiebig et al., 2010; Keane and Wasi, 2013). Recent studies in Hackbarth and Madlener (2016) and Hurtubia et al. (2014) have presented with real-life implications of this heterogeneous behavior.

Incorporating customer behaviors in RM and pricing decisions is a challenging task. Zhang and Bell (2010), Zhang et al. (2010), and Raza (2015b) have shown that price differentiation brings an additional profitability for a risk-neutral firm. Specifically, Zhang and Bell (2007), Zhang and Bell (2010), and Zhang et al. (2010) address the demand leakage effect between two pre-existing market segments; these studies however do not segment markets based on a differentiation price. In a contrast to these studies, Philips (2005) has numerically analyzed the problem of optimal price differentiation for price-dependent deterministic demand with demand leakage effects in which the cumulative market (share) demand is divided into two segment using a differentiation price. It is important to mention here that studies reported in Zhang and Bell (2010), and Zhang et al. (2010) determine joint pricing and inventory selection for each of the existing market segments while taking into the consideration of demand leakage effect. Whereas, Raza (2015b) extends the work in Philips (2005), and considers the problem of joint price differentiation and inventory selection with the cannibalization effect. Kim (2015) studied the impact of customer buying behavior on the optimal allocation decisions. Du et al. (2015) jointly explored optimal pricing and inventory management in the presence of strategic customers with risk preference and decreasing value. Zhou et al. (2015) developed a two period pricing model for new fashion style launching strategy. A joint advertising, pricing, and collection decisions in a closed-loop supply chain framework is presented in Hong et al. (2015).

1.1.3. Alternative objective models

Most studies have in the literature have only considered risk-neutral firms and pricing as an exogenous parameter. Lin and Kroll (1997) investigated the standard NVP with dual performance measures and quantity discounts. Parlar and Weng (2003) considered the bi-objective problem of maximizing the profit and the satisficing level with order quantity decision using a standard NVP framework. The satisficing level can be referred to as the aspiration level which is to maximize the probability of at least reaching the endogenous target profit. Brown and Tang (2006) studied the impact of alternative performance measures on an inventory policy and used NVP framework. Shi and Chen (2007) considered satisficing objectives in contracts for a supply chain and suggested pareto-optimal solutions. Ma (2008) researched general profit targets for a loss-averse NVP. Shi and Chen (2008) investigated pareto quantity flexibility contracts for a supply chain under multiple objectives. Recently, pricing decision was considered in Yang et al. (2011) along with the order quantity for a target oriented NVP.

Another form of an alternative objective is to consider the degree of risk or loss aversion performance measure. Keren and Pliskin (2006) proposed benchmark solutions for a risk-averse NVP. Chen et al. (2007) presented risk aversion as a performance criterion in the context of inventory management and adopted an NVP framework. Gotoh and Takano (2007) reported CVaR as a performance measure with a NVP framework. Other studies in Wang and Webster (2007) Choi et al. (2008), Taaffe et al. (2008), Chen et al. (2009b), Wang and Webster (2009), Wang et al. (2009), Wu et al. (2009), and Wei and Choi (2010) have also used loss-aversion performance measures such as mean variance analysis, Value-at Risk (VaR), etc. Arcelus et al. (2012) studied the degree of risk tolerance within an NVP framework with pricing and considered the satisficing objective in addition to profitability goals. Nooraie and Parast (2015) presented a multi-objective approach to supply chain risk management: Integrating visibility with supply and demand risk. Li et al. (2015) provided an agency and collaboration perspective on joint supply chain risk management. Wei et al. (2015) discussed refund policies for core with quality variation in OEM remanufacturing.

1.2. Contribution

The *main contribution* of this paper is in considering several important objectives while determining the optimal product prices