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Pricing and sales-effort investment under bi-criteria in a supply chain of virtual products involving risk

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ABSTRACT

This work develops a stochastic model of a two-echelon supply chain of virtual products in which the decision makers—a manufacturer and a retailer—may be risk-sensitive. Virtual products allow the retailer to avoid holding costs and ensure timely fulfillment of demand with no risk of shortage. We expand on the work of Chernonog and Avinadav (2014), who investigated the pricing of virtual products under uncertain and price-dependent demand, by including sales-effort as a decision variable that affects demand. Whereas in the previous work equilibrium was obtained exactly as in a deterministic case for any utility function, herein it is not. Consequently, we focus on the strategies of both the manufacturer and the retailer under different profit criteria, including the use of bi-criteria. By formulating the problem as a Stackelberg game, we show that the problem can be analytically solved by assuming certain common structures of the demand function and of the preferences of both the manufacturer and the retailer with regard to risk. We extend the solution to the case of imperfect information regarding the preferences and offer guidelines for the formation of efficient sets of decisions under bi-criteria. Finally, we provide numerical results.

1. Introduction

The last decade has seen a rapid increase in the market share and variety of virtual products. This increase is largely a result of the proliferation of digital platforms for content consumption, as well as the development of the internet as a direct channel for delivering goods and transferring payments (Waelbroeck, 2013). Foros, Kind, and Shaffer (2013), who investigate business formats of digital platforms, refer to the wholesale price contract as a common type of contract between manufacturers (e.g., content providers such as book publishers and developers of mobile applications) and retailers (e.g., Apple Store, Google Play, Amazon). Jeong, Khouja, and Zhao (2012) and Li and Liu (2013) analyze this type of contract for digital products. Examples of companies that have adopted this contract in practice include Amazon, which used it for many years to sell eBooks. Additional companies that apply the wholesale price contract for sales of virtual products include retailers who offer hotel bookings online. For example, according to Lytle (2014), some online travel companies, e.g., Expedia, sign contracts with hotels in which the hotel agrees to receive a fixed payment per night, and the online travel company charges a commission.

Our study focuses on pricing and sales-effort decisions in a supply chain of virtual products under uncertain demand and risk consideration. While pricing decisions have been thoroughly analyzed in the literature, the sales-effort investment decision is less explored. According to Xiao, Yu, and Sheng (2005), sales effort is important in stimulating demand and may constitute a significant portion of a firm's operating expenses. For comprehensive discussions of this issue see Taylor (2002) and Cachon and Lariviere (2005). The importance of joint decisions on pricing and sales effort is reflected in the recent literature. For example, He, Zhao, Zhao, and He (2009) investigate channel coordination for a supply chain facing stochastic demand that is sensitive to both sales effort and retail price, using a standard newsvendor setting with a supplier and retailer who are both risk-neutral. Both Xie and Wei (2009) and Aust and Buscher (2012) study vertical cooperative advertizing and pricing decisions in a manufacturer–retailer supply chain with deterministic demand. Wang, Wang, and Shou (2013) investigate a dominant retailer's optimal joint strategy of pricing and timing of effort investment and analyze how it influences the decision of the manufacturer, the total supply chain profit, and the consumers' payoff. Jin, Wang, and Hu (2015) investigate the issue of sales-effort decision rights under a wholesale

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price contract. They found that it is better for both the manufacturer and the retailer if one firm fully controls the market demand (e.g., through pricing and sales effort) and the other firm moves first. In contrast to our study, the papers above do not consider the risk sensitivity of supply chain members.

Recently, Chernonog and Avinadav (2014) investigated the pricing of virtual products under a wholesale price contract. Their work was based on the premise that the stochastic nature of demand exposes the supply chain members to financial risk, and that each party adopts profit criteria that reflect his or her attitude towards this risk. The authors showed that, when stochastic demand follows a multiplicative form, the pricing decisions that maximize the expected profit also maximize all the investigated profit criteria—and, in fact, any utility function of the profit. We expand the two-echelon supply chain model of Chernonog and Avinadav (2014) in two directions. First, we consider the effect of the retailer's sales-effort investment on the model. Introducing the sales-effort investment as a decision variable of the retailer results in an equilibrium that is sensitive to the retailer's utility function. This result differs from that of Chernonog and Avinadav (2014), in which equilibrium was obtained exactly as in a deterministic case for any utility function. Second, we consider bi-criteria decision making in a two-echelon supply chain. In Chernonog and Avinadav (2014), in contrast, bi-criteria analysis is carried out for only one decision maker without a game approach.

The main contribution of this paper is in analyzing the decisions of the supply chain members in a framework of a game under bi-criteria. We find that bi-criteria preferences of the retailer introduce a new source of uncertainty in addition to the demand uncertainty. To further explore this case, we analyze it from two perspectives: perfect and imperfect information regarding the retailer's choice mechanism. Under the assumption of perfect information, the probabilistic choice theory (Swait & Marley, 2013) is used, whereas under imperfect information, normative (Fishburn, 1981) and behavioral (Maskin, 1979) approaches are used. In order to simplify the solution under the imperfect information assumption, we propose an innovative technique for finding the efficient set of wholesale prices for any utility function of the manufacturer.

2. Model formulation

Similarly to Chernonog and Avinadav (2014), we develop a model of a manufacturer who distributes a virtual product to customers via a retailer. The sales volume of such products matches the demand, as virtual products can be produced with ample capacity and no need for inventory. The manufacturer (he) determines the wholesale price per unit, w. The retailer (she) determines her margin, m, so that the retail price to the customer is $p = m + w$. In contrast to Chernonog and Avinadav (2014), the retailer also determines her sales-effort investment, e. We assume that the demand function for the virtual product is $\tilde{D}(p, e) \equiv D(p, e)\varepsilon$, where $D(p, e)$ is the expected demand as a function of the retail price and the sales-effort investment (e.g., Aust & Buscher, 2012; Lau, Su, Wang, & Hua, 2012; SeyedEsfahani, Biazaran, & Gharakhani, 2011; Wang et al., 2013) and ε is a non-negative random variable ($E(\varepsilon) = 1$), which is independent of p and e.

Let $F_\varepsilon(\cdot)$ be the cumulative distribution function (CDF) of ε. As is common in economics, $D(p, e)$ is decreasing in p for any given e. We also assume that $D(p, e)$ is increasing in e for a given p.

Since demand is random, the profit of the manufacturer is also random and follows

$$\tilde{\pi}_M(w) \equiv \pi_M(w)\varepsilon, \tag{1}$$

where

$$\pi_M(w) = wD(m + w, e) \tag{2}$$

is the expected profit. The objective of the manufacturer is to maximize the expected utility of his profit by controlling w.

Similarly, the retailer's profit is also random and follows

$$\tilde{\pi}_R(m, e) \equiv mD(m + w, e)\varepsilon - e. \tag{3}$$

Consequently, the retailer's expected profit is

$$\pi_R(m, e) = mD(m + w, e) - e. \tag{4}$$

The retailer's objective is to maximize the expected utility of her profit by setting m and e.

Similarly to Chernonog and Avinadav (2014), we state:

Theorem 1.

(i) The wholesale price per unit w that maximizes $\pi_M(w)$ maximizes the expected value of any utility function of the manufacturer's profit.
(ii) The margin m that maximizes $\pi_R(m, e)$, for a given e, maximizes the expected value of any utility function of the retailer's profit.

Proof. See Appendix.

The insight provided by Theorem 1 is that the manufacturer should determine his wholesale price exactly as in a deterministic demand model (i.e., select the value of w that maximizes $\pi_M(w)$), regardless of his attitude toward risk or the distribution of ε. It implies that the retailer's strategy is independent of the manufacturer's utility function.

The following lemma implies that stochastic dominance of the retailer's profit does not exist with respect to e for given values of w and m.

Lemma 1. *Given e_1, e_2 and m, the corresponding CDFs $F_{\tilde{\pi}_R(m,e_1)}$ and $F_{\tilde{\pi}_R(m,e_2)}$ cross each other so that neither profit stochastically dominates the other.*

Proof. See Appendix.

Lemma 1 shows that, in contrast to Chernonog and Avinadav (2014), it is essential to consider the utility function of the retailer. Denoting the retailer's utility function by u, the problem of the retailer is

$$\max_e \left\{ \max_m \{E[u(\tilde{\pi}_R(m, e))]\} \right\}. \tag{5}$$

Furthermore, the retailer, for a given e, should determine her margin exactly as in a deterministic demand model (i.e., select the value of m that maximizes $\pi_R(m, e)$), regardless of the distribution of ε. Thus the problem can be solved in two stages:

$$\max_e \{E[u(\tilde{\pi}_R(m_e, e))]\}, \tag{6}$$

where

$$m_e = \arg\max_m \{mD(m + w, e)\}. \tag{7}$$

The decisions of the two parties are interrelated as in a noncooperative game, where the manufacturer is the leader of the supply chain. We assume, a priori, a game with perfect information, in which both players are aware of the demand function and of the supply chain members' risk preferences (see, for example, Chernonog & Kogan, 2014; Xie, Yue, Wang, & Lai, 2011). This type of game is also known as a Manufacturer Stackelberg (MS) game.

In the MS game, the manufacturer knows that if he determines a certain value of w then the retailer will respond by choosing the values $[m(w), e(w)]$ that maximize $E[u(\tilde{\pi}_R(m, e))]$. Hence, the manufacturer's strategy is to select the value of w that maximizes $\pi_M(w)$, subject to $m = m(w)$ and $e = e(w)$. This strategy is denoted by w^{MS}. The sequence of decisions in the MS game implies that the manufacturer has to know the retailer's attitude toward risk and the distribution of ε.