Int. J. Production Economics 158 (2014) 54–64

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Analysis of protection and pricing strategies for digital products under uncertain demand

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ARTICLE INFO

Article history:
Received 1 August 2013
Accepted 20 July 2014
Available online 25 July 2014

Keywords:
Protection of digital product
Pricing
Supply chain
Stochastic dominance
Game theory

ABSTRACT

We analyze pricing and protection (digital rights management) strategies in a two-echelon supply chain that consists of a manufacturer and a retailer of digital products. The demand for the legal (non-pirated) product, which depends on both price and monetary investment in protection, is assumed to be uncertain. Three different supply chain models are analyzed: manufacturer Stackelberg, retailer Stackelberg and vertical integration. We show that the retailer's utility function has no effect on the equilibrium strategies, and suggest schemes to find these strategies for any utility function of the manufacturer. Further results are obtained under assumptions of either a multiplicative or an additive demand model. We study the players' strategies under different profit criteria reflecting different attitudes toward risk—specifically, the Expectation criterion and the Target criterion—and, for each criterion, we obtain the dependence between the pricing and the protection investment. We show that there are situations in which the manufacturer can increase his profit by giving up his leadership to the retailer, even if the power balance is in his favor.

1. Introduction

Manufacturers of digital products such as software programs, digital music files and videos often implement digital rights management (DRM) systems designed to control how end-users can install, copy, or duplicate these products. Well-known examples of DRM systems include Microsoft's requirement of an activation code for its Windows operating system; an e-book server that restricts access to, copying of and printing of material in accordance with constraints set by the copyright holder of the content; and a movie studio that includes software on its DVDs that limits the number of copies a user can make (for additional examples of DRM implementation, see Djekic and Loebbecke (2007) and Jain (2008)). Therefore, manufacturers who invest in DRM systems can potentially mitigate digital piracy by increasing the cost of copying digital products (Sundararajan, 2004; Ahn and Shin, 2010) and, correspondingly, increase customer demand for legal products. Indeed, Belleflamme and Peitz (2010) suggest that "DRM should not simply be considered as a tool to protect against piracy, but rather as a key to opening up the market".

The positive effect of DRM investment on customer demand is similar to that of other demand accelerators such as rebate, advertising, and quality (see a comprehensive survey of demand functions in decision modeling in Huang, Leng and Parlar (2013)). Sundararajan (2004) and Ahn and Shin (2010) argue, however, that beyond a certain level of protection, DRM systems may decrease the value of the original product, as it is perceived by consumers. This type of negative effect might occur, for example, because software encryption increases file size and thereby increases download times, or because an application's restrictions prevent a customer from installing the application on all of his or her devices. This non-monotonic effect of DRM investment distinguishes it from other demand accelerators.

In this paper we consider pricing and DRM investment in a two-echelon supply chain comprising a single manufacturer of a digital product and a single retailer, who distributes the product to end-customers. Both parties wish to maximize their own profit. As is common in practice, the manufacturer alone determines how much to invest in DRM, whereas the retail price of the product is affected by both the manufacturer and the retailer. In the standard economics literature this vertical relationship is usually analyzed by a game approach, focusing on the interaction between the supply chain members and the resulting supply chain performances (Kogan and Tapiero, 2007). Different types of games reflect different power balances between the players and different sequences of their decisions: (i) a symmetrical power balance yielding a game of simultaneous decisions (see, for example, Choi, 1991; SeyedEsfahani et al., 2011); (ii) leadership of either the manufacturer or the retailer with sequential decisions—such scenarios are commonly modeled using Stackelberg games (see, for example, Lau and Lau, 2005; Xie et al., 2011); (iii) the case of a manufacturer and a retailer who act in cooperation and bargain for the division of profits—this case is

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http://dx.doi.org/10.1016/j.ijpe.2014.07.021
0925-5273/

reflected in bargaining game approaches (see, for example, Aust and Buscher, 2012; Xie and Wei, 2009).

We focus on the case of asymmetric power balance between the manufacturer and the retailer of a digital product and the effect of this power balance on equilibrium prices and DRM investment. Specifically, we consider two models. The first model, which is based on the Manufacturer-Stackelberg (MS) game, assumes that the manufacturer is the leader. This model reflects, for example, the case of Microsoft, a software manufacturer that dominates the market and is much larger than the retailers selling its products. The second model, which is based on the Retailer-Stackelberg (RS) game, assumes that the retailer is the leader. This model reflects, for example, the case of Apple, a retailer of music and smart-phone applications (sold through the iTunes store) that is much larger and more dominant than most of the content manufacturers (e.g., artists, developers, etc). We also consider as a benchmark a single-echelon model, which represents an integrated firm that does both manufacturing and retailing (see, for example, Lau and Lau, 2005; Xie et al., 2011). This model represents companies such as Skype and RealPlayer, which distribute their for-pay software offerings directly to customers via the internet.

In reality, demand is, naturally, a random variable due to various sources of future uncertainty (e.g., seasonality, changes in customers' tastes, introduction of competitive products and technological developments). As a result of the stochastic nature of demand, the manufacturer and the retailer are exposed to financial risks, and the two parties make their decisions according to their respective attitudes toward risk. We use utility functions to express these attitudes. This includes, obviously, the case of a linear utility function, which yields the Expectation criterion. In addition, we analyze the models using the Target criterion, in which the objective is to maximize the probability of achieving a certain profit. Our choice of the Target criterion is primarily motivated by the importance of meeting a profit target in business practice, and specifically in the context of digital products. For example, according to Bloomberg Businessweek (http://www.businessweek.com/news/2013-04-22/nintendo-ceo-seen-missing-profit-target-as-wii-u-founders), Nintendo's profit target for 2013 was 14 billion yen from selling game software. Likewise, Microsoft adopts quarterly targets, which it announces publicly and then attempts to exceed (see http://www.financialexpress.com/news/microsoft-q1-profit-beats-forecasts-reports-strong-sales-in-office-and-server-software/1187080).

We analyze how the supply chain members' attitudes toward risk affect their pricing and DRM investment decisions. In particular, we show that the retailer's utility function (or any other increasing function of her profit) has no effect on the optimal choices of either price or DRM investment. This result is due to the existence of stochastic order (see Whitmore and Findlay, 1978) among the random variables of profits. On the other hand, the manufacturer's attitude toward risk cannot be excluded from the decision-making process. Two additional interesting results obtained in this study are (i) when the manufacturer is target oriented, he can postpone his DRM investment decision until after the pricing decisions are made; in addition, the optimal retail price obtained under this scenario is higher than or equal to that obtained under a risk-neutral manufacturer; and (ii) in some cases a risk-neutral manufacturer can attain higher profits in the RS game than in the MS game. The latter result is counter-intuitive since it claims that leadership is not necessarily an advantage, and that it might be beneficial for the manufacturer to deliberately ask the retailer to take initiative and determine her margin first.

2. Literature review

Previous research related to this paper can be broadly grouped into four categories. The first category consists of literature on pricing and protection strategies of digital products. The pioneering paper of Conner and Rumelt (1991) analyzed protection and pricing strategies in the presence of network externalities, when the consumer's utility from the digital product increases with the number of its users. Prasad and Mahajan (2003) developed a continuous-time, infinite-horizon diffusion model with demand saturation and immediate piracy. They showed that a monopoly should start with minimum protection of its software, but impose maximum protection well before the product has diffused to half the market. Sundararajan (2004) analyzed an optimal pricing and DRM protection policy for a monopolist who uses price discrimination among heterogeneous customers. As for the protection level, he showed that the monopolist may find it optimal to choose an intermediate protection level, owing to the potentially negative effects of protection that exceeds a certain level. Khouja and Smith (2007) analyzed optimal pricing and protection policies of a monopolist who can invest either in technology or in copyright enforcement to reduce piracy. Ahn and Shin (2010) analyzed the optimal level of DRM under the assumption that stronger DRM makes copyright infringement more difficult, but at the same time decreases the value of the legal product for users. They showed that in some cases, forgoing DRM is the optimal strategy for the firm. Kogan et al. (2013) studied pricing and protection strategies aimed at enabling firms to recoup profits affected by piracy. The researchers showed that in some cases, fully pricing out piracy might not be the manufacturer's optimal strategy.

The second category of research refers to utility functions and other profit criteria under uncertainty, and specifically to the Target criterion. Extensive research suggests that firm managers seek to achieve satisfactory objectives, termed "satisficing" by Simon (1959), rather than to maximize their expected utility of profit (e.g., Lanzillotti, 1958; Morris and Fuller, 1989; Merchant and Manzoni, 1989; Brown and Tang, 2006). Shi et al. (2010) suggest that these objectives are "more practical for many individuals and firms. E.g., in the business world, it is common that individuals and firms are rewarded if they can meet or exceed some preset profit targets". The Target criterion is commonly used as a satisficing objective both in the literature and in practice (see Lau, 1980; Bordley and LiCalzi, 2000; Parlar and Weng, 2003; Bordley and Kirkwood, 2004; Abbas and Matheson, 2005; Shi et al., 2010; Shi et al., 2011; He and Khouja, 2011).

The third category of research we draw from refers to stochastic dominance of distributions. In general, if a random variable X stochastically dominates a random variable Y, denoted by $X \succ Y$, then $P(X \leq z) \leq P(Y \leq z)\ \forall z$. The usage of stochastic dominance can be found in literature on inventory theory (Karlin, 1960; Bulinskaya, 2004; Yeo and Yuan, 2011), in evaluations of distributions of security returns (Hadar and Russell, 1971), in rankings of income distributions (Saposnik, 1981, 1983), in rankings of nutrition distributions of individuals (Kakwani, 1989), in rankings of firms (Kocas and Kiyak, 2006), and in decisions in business planning and investment (Duarte, 2001; Wong, 2007; Egozcue and Wong, 2010; Ma and Wong, 2010). In this paper, we use stochastic dominance to evaluate the profit distributions of the retailer and manufacturer. It is known (e.g., Levy, 1992) that if one profit distribution stochastically dominates another, then it is preferred by all utility functions.

The fourth category of research we rely on refers to the structure of the demand function. Early studies in the field of supply chain research tended to assume that the market demand for a given product is determined according to a single variable—the unit retail price. Recent studies, on the other hand, have increasingly begun to acknowledge additional factors that may affect demand (for a comprehensive survey of demand functions in decision modeling see Huang et al. (2013)). Most of these studies assume that demand is affected by price and by one additional factor, where the effects are separable. Two models