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Decision Support

On the optimal frequency of multiple generation product introductions

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ABSTRACT

This paper considers a firm that introduces multiple generations of a product to the market at regular intervals. We assume that the firm has only a single production generation in the market at any time. To maximize the total profit within a given planning horizon, the firm needs to decide the optimal frequency to introduce new product generations, taking into account the trade-off between sales revenues and product development costs. We model the sales quantity of each generation as a function of the technical decay and installed base effects. We analytically examine the optimal frequency for introducing new product generations as a function of these parameters.

1. Introduction

Products in competitive markets such as smart phones, tablets, computers, cameras, software, health and beauty products, and the like are usually offered as multiple generations. Various factors drive the development of successive product generations. First, the continuous and rapid technology improvements make it necessary to renew product generations frequently to stay competitive. Second, customers develop new needs over time. Third, in a relatively saturated market, new generation products can generate repeat purchases. For example, Elmer-DeWitt (2013) reports that “90 percent of iPhone 5S/5C buyers were upgrading from another version of the iPhone compared to 83 percent for the iPhone 5 launch and 73 percent for the iPhone 4S.” Erhun, Concalves, and Hopman (2007) point out that “managing the interplay between product generations can greatly increase the chances for success.” This is also supported by an empirical study across a wide range of industries in Morgan, Morgan, and Moore (2001), which shows that the introduction of multiple product generations is likely more profitable (26 percent higher) than a series of single-product generation introductions, and (40 percent higher) than a pure single-product generation introduction.

It appears that successive generations of many products are introduced in the market at regular time intervals. For example, Apple launched a new iPhone generation (around July–September) every year from 2007 to 2013. Likewise, between 2005 and 2013 a new generation of iPod Nano was introduced each September (except in 2011). Similarly, four generations of iPod touch were introduced each September from 2007 to 2010, and the fifth generation came to the market in October 2012. Moreover, in the automobile industry, Honda introduces a new generation of Accord each four to five years while Toyota brings a new generation of Lexus ES to the market circa every five years. This so-called time-pacing product development (PD) strategy has been widely recognized in the literature about other industries as well. Christensen (1997) shows that thanks to a time-pacing strategy, the medical technology company Medtronics was able to reduce uncertainty and improve the new PD process by eliminating requests for revisions to product features during the design process. Eisenhardt and Brown (1998) show that for rapidly shifting industries, a time-pacing PD strategy can improve the transition between new PD projects. Intel releases its chips with an approximately three-year cycle, and Morgan et al. (2001) point out that this strategy “allows it to profit from the investment it has made in developing and commercializing each generation while limiting competitions’ abilities to win sales”. Also, Souza, Bayus, and Wagner (2004) find that a time-pacing strategy “is not necessarily optimal, but generally does perform well under many conditions.” In this paper, we adopt the time-pacing PD strategy as a modeling assumption.

The process for phasing out an older product generation and introducing a new one in the market is called product rollover. A firm can choose one of two transition strategies during product rollover: phase-out transition or complete replacement. Using the phase-out strategy, old and new generations coexist in the market until sales of the old generation(s) drop to zero. Using the complete replacement strategy, a new generation product introduced in the market replaces in full the old generation product. These two strategies are also referred to as “dual-product roll” and “solo-product roll”,

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respectively (Billington, Lee, & Tang, 1998). In this paper, we assume that the firm adopts the complete replacement strategy. This assumption is supported: For example, Hewlett-Packard totally replaced DeskJet 500 printers with DeskJet 510 printers (Lim & Tang, 2006); Microsoft stops selling older software versions as soon as a new version is released; Google stopped selling Nexus 4 when launching Nexus 5 in September 2013, and so on. Consequently, the assumption of a complete replacement strategy is widely used in the literature (e.g., Arslan, Kachani, & Shmatov, 2009; Carrillo, 2005; Cohen, Eliashberg, & Ho, 1996, 2000).

We consider a firm that adopts a complete replacement strategy to introduce multiple generations of a product at regular time intervals within a given planning horizon. All product generations are assumed to be sold in the same geographical region and through the same channel. For each product generation, a PD cost is charged, and the sales quantity is related to the technical decay and the installed base effects. As technologies currently develop faster, the gap between the technology content of a certain product and the latest available technology increases over time. This gap precipitates the product gradually toward obsolescence and thus it loses its attractiveness to customers, we called this phenomenon "technical decay effect". We use the term "installed base effect" to refer to the combination of several social contagion effects: word-of-mouth, network effects, social preferences and observation learning (Narayanan & Nair, 2013). We consider diffusion dynamics by taking into account the installed base effect which allows the current sales rate to depend on the cumulative sales quantity.

The firm's objective is to maximize the sum of the profits of each product generation, which equals the sales revenue less the PD cost. To achieve the optimal total profit, it is important to decide on the optimal frequency of product introductions. If products are introduced too frequently, this may result in excessive PD costs. Moreover, as the time in the market is too short, each generation may experience poor sales, since there is insufficient time to build an installed base and reach peak sales. If a product generation stays in the market for too long, the technical decay effect may lead to a decrease in sales rate because customers are less willing to buy technically outdated products such as old generation computers with Intel 4004 chips for instance.

Our main contribution is to explicitly model diffusion dynamics and at the same time analytically study the optimal frequency of product introductions and its sensitivity to key model parameters. We model the PD cost based on the PD function in Druehl, Schmidt, and Souza (2009). To estimate product sales, we construct a primal sales model as a function of the various parameters mentioned above. We derive analytical results on the optimal frequency of product introductions and provide analytical sensitivity analysis of the impacts of different parameters on the optimal frequency and on the maximum total profit. Moreover, we extend our sales model, which allows a closed-form solution for the optimal frequency under some special conditions. We prove the uniqueness of the optimal frequency under general conditions. Finally we compare the sensitivity analyses between the primal and the extended sales models.

The rest of this paper is organized as follows. We review related literature in Section 2. In Section 3 we present the PD cost model, our primal sales model and the total profit function. In Section 4 we analyze the optimal product introduction frequency and parameter impacts. In Section 5, we present the extended sales model and analytical results. We conclude and discuss future research directions in Section 6. Proofs are provided in the Appendix. Proofs for Section 5 are provided as e-version due to the page limit.

2. Literature review

Our work is related to the literature on new product introduction (NPI). This literature has mainly focused on the product development and introduction of single product generation. Several papers consider multiple product generations and examine decisions during the product rollover as we do, by adopting "dual-product roll" or "solo-product roll" strategy (Billington et al., 1998).

Research focusing on single product generation introduction primarily studies the static trade-off between time-to-market and product performance (such as Bayus, 1997; Klastorin & Tsai, 2004; Krishnan & Ulrich, 2001; Savin & Terwiesch, 2005). Ozer and Uncu (2013) develop a dynamic decision-support tool to optimize the nested two-stage decisions on the time-to-market and product quantity for a component supplier. Ozer and Uncu (2015) extend their research to also integrate pricing and sales channels into decisions. Unlike their literature, the nature of our problem is such that multiple product generations are introduced to the market.

The research area of multiple generation products introduction can be classified into two steams according to the rollover strategies adopted. One stream assumes both old and new product generations to be sold during the transition period (dual-product roll). Studies in this stream consider the cannibalization effect or switch-over among old and new generations and address decision about time (e.g., Lim & Tang, 2006), price (e.g., Li & Graves, 2012), inventory quantity (e.g., Li, Graves, & Rosenfield, 2010), etc. Druehl et al. (2009) is the most closely related to our research. Both papers consider diffusion effect, adopt time-pacing strategy, examine the optimal pace of product introduction and analyze the parameter impacts. However, by adopting "dual-product roll" strategy and the Norton–Bass diffusion model, their model necessitates numerical approach due to the analytical complexity. Instead, under the "solo-product roll" assumption, our sales model keeps the analytical tractability, which differentiates the present paper from Druehl et al. (2009).

In the same vein as our research, another stream of the literature on multiple generation products introduction assumes a single generation in the market at any time (solo-product roll). Some papers examine product introduction decisions under competitive environment in a duopoly (e.g., Arslan et al., 2009; Cohen et al., 1996, 2000; Morgan et al., 2001; Souza, 2004; Souza et al., 2004), while others consider a monopoly as we do in our paper (e.g., Carrillo, 2005; Krankel, Duenyas, & Kapuscinski, 2006; Liu & Ozer, 2009; Wilhelm & Xu, 2002). Liu and Ozer (2009) is closely related to our work. We both show that the pace of technology evolution negatively impacts the firm's total profit, and a smaller product replacement cost encourages more product replacements. We model the relation between a product's profit and its performance gap (technical decay) in different ways; the product replacement cost in their model is fixed while our PD cost depends on the decision variable (product introduction frequency). More importantly, we consider the diffusion dynamics and explicitly discuss the impacts of diffusion speed and staff's specialization level on the optimal frequency and the total profit. However, unlike ours, they propose a model that helps a manager dynamically decide whether and when to adopt uncertain technological changes. Carrillo (2005) and Krankel et al. (2006) consider diffusion but they rely on numerical implementation and dynamic programming, respectively.

To the best of our knowledge, we are the first to analytically study the frequency of multiple generation product introductions while explicitly taking into account the diffusion effect. The diffusion effect has been widely observed in practice and extensively studied in the literature (Mahajan, Muller, & Bass, 1990; Meade & Islam, 2006). However, due to the analytical complexity of extant diffusion models for multiple generations (such as Mahajan & Muller, 1996; Norton & Bass, 1987), analytical results are not obtained by the literature of multiple generation product introduction considering the diffusion effect (such as Carrillo, 2005; Druehl et al., 2009; Krankel et al., 2006). We develop our sales model which considers diffusion and holds flexible shapes, and we provide analytical results for the optimal frequency and parameter impacts.