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Analysis of industry equilibria in models with sustaining and disruptive technology

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ABSTRACT

This paper analyzes a special type of technology evolution, referred to in the literature as *disruptive* technology vs. *sustaining* technology. In general, "old" products based on sustaining technology are perceived to be superior to the "new" ones based on disruptive technology. However, the latter have distinctive features that allow them to attract an exclusive set of customers. Examples include notebooks vs. netbooks, hard-disk drives vs. solid-state drives, laser printers vs. inkjet printers, etc. We consider a model with an established firm and an entrant firm that have heterogeneous product-offering capabilities: the established firm can offer either or both types of products, while the entrant firm can only offer new products. Firms make capacity, pricing, and quantity decisions that maximize their ex-ante profit. Within this framework, we analyze deterministic games with perfect information and stochastic games with uncertain valuation of the disruptive technology. Equilibrium decisions are discussed under various market conditions, as well as under dedicated vs. flexible capacity assumptions.

While over-investment and over-production may occur in a stochastic game with dedicated capacities, the equilibrium capacity decisions seem to be more "rational" if the established firm utilizes flexibly capacity, or if the dedicated capacity can be converted ex-post (albeit at some expense).

1. Introduction

In October 2007, ASUS unveiled its first netbook computer—Asus Eee PC 701, a mini-laptop-like gadget with 7-inch display, keyboard 15% smaller than the traditional one, Intel Celeron 900 M processor, 512 MB of RAM, and up to 16 GB solid-state hard drive. These features were far below the standard laptop configurations at that time, in which processors were usually twice as fast, RAMs four times as large, and hard drives had capacity going up to 500 GB. However, during the first quarter after its release, the sales of Eee PC 701 surged up to 350,000 units (Engadget.com, 2007). This triggered other laptop manufacturers, such as Dell and Acer, to offer their own netbooks as well. By the end of the third quarter of 2008, the sales of netbooks grew 160% and were taking market shares away from the laptop computers (DisplaySearch.com, 2008).

Despite their less-than-regular-sized screens and keyboards, their lack of computation capability, and their limited storage space, netbooks have some merits that deserve to be mentioned. In the first place, they are extremely light—the Asus Eee PC 701 weighs just slightly over 2 lb, compared to the standard laptops which are typically more than twice as heavy (e.g., 14" Thinkpad T 60 weighs around 5.2 lb). Netbooks also come with irresistible price tags: Asus Eee PC 701 started from $250, which amounted to less than 30% of the average amount paid for a laptop.

The idea of netbooks has its "... roots in the One Laptop per Child (OLPC) project championed by former MIT media director Nicholas Negroponte; the original idea was to create a low-cost PC that would give young people access to the Internet and help kids in emerging markets access the world of information and communication on the Internet. (PCMagazine.com, 2008)" Moreover, for business customers netbooks act like travel companions that possess strong mobile communication ability (but cannot fulfill the need for sophisticated computations) without adding much weight to their luggage. In addition, companies may benefit from significant savings on IT procurement through this alternative (Reuters.com, 2009; ZDNetAsian.com, 2009). Thus, netbooks gain their market share by sacrificing computation capability in return for mobility and cost-saving.

In recent decades, many industries have experienced similar technology evolutions, in which a new technology traded off *core-function* performance for evolutionary *side-function* improvements. For instance, in the mid-'1980s, when the 3.5-inch hard-disk drive (HDD) was introduced in the market that had previously been dominated by the 5.25-inch HDD, it sacrificed capacity to achieve greater portability, and more recently solid-state-drives (SSDs) were introduced in the market dominated by HDDs, and

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they traded off capacity, writing speed, etc. to achieve less noise and greater temperature tolerance. One can think of numerous similar examples—ink-jet printers vs. laser printers, on-line retailing vs. mortar-and-brick retailing, Voice-over-Internet Protocol (VoIP) phones vs. landline services, hybrid electric vehicles vs. regular vehicles, to mention just a few. Christensen (2003) introduced the terms *sustaining technology* and *disruptive technology* to describe such phenomena:

> Most new technologies foster improved product performance. I call these *sustaining technologies*. (...) What all sustaining technologies have in common is that they improve the performance that mainstream customers in major markets have historically valued. ...*disruptive technologies* emerge: innovations that result in *worse* product performance, at least in the near-term. (...) But they have other features that a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and frequently, more convenient to use. (Christensen, 2003, p. xviii).

As disruptive technology does not usually provide a "better" product at the very beginning, it can often be dismissed by incumbent firms who at that time provide "better" products. However, disruptive technology does serve an emerging market that is not covered by the sustaining technology—teenagers who cannot afford a full-size laptop, home users who cannot afford the price of an inkjet printer, environmentalists that fervently support hybrid electric cars, etc. Moreover, as the disruptive technology itself improves, the functionalities that have been sacrificed early on may improve and disruptive technology may enter the existing market of sustaining technology. A good example would be digital cameras, which today dominate the film cameras, and some key camera manufacturers had already announced discontinuing their film camera lines (New York Times, 2006). Failing to recognize the hidden threat of disruptive technology can have severe consequences, as illustrated by the bankruptcy of Polaroid in 2001, which was in great extent due to neglect of the emerging digital market. Thus, in the presence of sustaining and disruptive technologies, the firms are confronted with the following questions:

1. Should an established firm with sustaining technology introduce the disruptive technology at the same time?
2. How should established and entrant firms make their operational investment decisions in a riskless environment?
3. How does the uncertainty in disruptive technology affect operational decisions of both firms?

2. Literature

The concept of disruptive technology was introduced in the early 1990's (Christensen, 1992; Bower and Christensen, 1995). During the following ten years, Christensen (2003), Christensen and Raynor (2003), and Christensen et al. (2004) documented many ups and downs faced by the firms whose business was conducted in the presence of disruptive technology. They argue that incumbent firms with sustaining technology may fail due to inefficient resource allocation between the original sustaining technology and the new disruptive technology. Some of the authors call for more constructive frameworks and rigorous theories in better conceptualization of these ideas (Danneels, 2004; Christensen, 2006).

While most research on this topic falls in the area of strategy (e.g., Christensen et al., 2000; Gilbert and Bower, 2002) or empirical analysis (e.g., Agarwal and Bayus, 2002; De Figueiredo and Silverman, 2007), there are a few recent modeling papers as well. Schmidt and Porteus (2000a) studied incomplete substitution between products based on disruptive and sustaining technology with decentralized firms or a centralized firm. Adner and Zemsky (2005) analyzed how the threat of disruptive technology depends upon various factors including the numbers of firms, and the corresponding impact on different aspects of the industry. Van der Rhee et al. (2007) examined how firms in a duopoly make their technology adoption decisions under different market conditions. Druehl and Schmidt (2008) compared different encroachment strategies for firms to harness the disruptive technology at the same time with the sustaining technology.

In most of these papers, firms are restricted to adopt only one type of technology. Schmidt and Porteus (2000b) modeled a game between an incumbent and an entrant, in which they examined how capability for cost reduction and innovation affect the equilibrium investment decisions. Adner and Zemsky (2005) in their extension discussed multi-technology firms. Both papers imply that firms will choose only one type of technology in an equilibrium, even if they are allowed to apply both technologies at the same time. Schmidt and Porteus (2007) studied how complementary assets may affect firms' investment and pricing decisions.

Our paper differs from the existing literature in several respects. First, we look at firms with heterogeneous product-offering capabilities, by allowing the incumbent to adopt either or both technologies, while restricting the entrant to work with disruptive technology only. We believe that it is important to make a distinction between established and entrant firms in their ability to offer different types of technologies—as the sustaining technologies are more mature and their markets are usually dominated by strong players, an entrant may simply choose to start with alternative technologies. On the other hand, disruptive technologies are likely to have lower entry barriers, which makes them easier to implement by either firm.

Second, we address capacity decisions, which are critical from the operations management perspective, but have not yet been explored within the current framework of disruptive technology. Capacity constraints may have a great impact on equilibrium outcomes. As noted by Kreps and Scheinkman (1983), a capacity-constrained Bertrand game may yield the same equilibrium as a corresponding Cournot game (unlike the uncapacitated game, which may leave both firms with zero profit). We apply a similar idea in our game with a two-product duopoly market, and we identify the corresponding equilibria. In our model, the equilibrium may consist of both firms simultaneously offering products based on disruptive technology, at the same price level. This is in contrast to some previous results (Schmidt and Porteus, 2000b; Adner and Zemsky, 2005), in which the established firms would only select one type of technology given the choice of two.

Finally, we study the impact of uncertain disruptive technology on operational decision making. Capacity reservation and production postponement (see, e.g., Van Mieghem and Dada, 1999; Spinler and Huchzermeier, 2006; Jin and Wu, 2007; Anupindi and Jiang, 2008) as well as flexible capacity (see, e.g., Fine and Freund, 1990; Van Mieghem, 1998; Chod and Rudi, 2006) are not new in literature. However, to our knowledge we are the first to analyze the game in which two parties have asymmetric product portfolios.

The paper is organized as follows. We first introduce our model in Section 3. Section 4 studies two deterministic games: one with dedicated capacity and the other with flexibly capacity; in Section 4.2, we discuss the impact of model parameters on equilibrium outcomes and illustrate analytical findings with numerical examples. Section 5 extends the analysis from Section 4 by introducing uncertainty into the valuation of disruptive technology—three stochastic games are discussed with various assumptions on the flexibility level of the capacities. We conclude in Section 6, and due to space constraints we present all proofs in the on-line technical appendix.