DECISION MODELS FOR GROWING FIRMS:

OBSTACLES AND OPPORTUNITIES

by

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Abstract

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This dissertation is comprised of three essays. The first, "Optimal Marketing Strategies for Competing New Ventures in a Nascent Industry" has been originally accepted for publication in the *International Journal of Entrepreneurship and Innovation Management*. It considers new ventures that are pioneering a nascent industry. Just as their established counterparts do, these ventures strive to increase profit by acquiring sales of rival new ventures. However, new ventures can also grow by attracting unrealized sales. The essay investigates the resulting tradeoff in marketing expenditures via a differential game between two competing new ventures. Extensive numerical analysis suggests that an increase in a new venture's unit profit margin, effectiveness in gaining new sales, or initial sales level, but a decrease in sales decay, may cause a positive spillover for its rival.

The second essay, "Integrating Customer Preferences with Technology Adoption and Product Redesign in a Duopoly" focuses on a firm's decision to add a technology that changes how customers interact with the firm's product. We formulate a two-stage game-theoretic framework to investigate the conditions under which two competing firms should add a technology, and how a firm that adopts

technology should redesign its product to incorporate technology. We investigate how prospective and existing customers' preferences for the technology and the product-technology fit should affect the firm's adoption and product redesign decisions. We articulate conditions for the existence of a Nash equilibrium where both firms add technology, and demonstrate that customer preferences for technology standardization may actually impede standardization.

The third essay, "New Product Positioning for a Segmented Market" focuses on how competing firms should set price and quality for a new technologically-advanced product. The targeted market is comprised of two customer segments that differ in innovativeness. We analyze a closed-loop Stackelberg game with perfect information and find that a late entrant's ability to challenge an incumbent is most affected by production cost. If a firm has a large enough production cost advantage relative to its rival, it can attract customers from both segments; however, such a firm should not necessarily be the first mover.

Chapter 1

Optimal Marketing Strategies for Competing New Ventures in a Nascent Industry

1.1 Introduction

In mature industries, firms invest in advertising to steal the customers of their competitors. The targeting of another firm's sales to gain market share can be quite aggressive. Microsoft's campaign against AOL in the Internet service provider (ISP) market provides a good example. AOL had become an early market leader among ISPs by offering subscribers an easy-to-use product. Microsoft began offering an application that transferred e-mail addresses and calendars from the AOL program to the MSN program, in addition to other benefits specifically targeting AOL subscribers (Hu, 2002).

However, in a *nascent industry*, in which the product itself is still in its introduction or growth phase and industry sales are low, new business ventures also invest in marketing expenditures to "create" customers by successfully targeting the pool of potential new customers. In this article, we characterize the pool of potential new customers as *unrealized customers* until they are attracted to a new venture and become *realized customers*. Once an unrealized customer purchases from a new venture, all nascent industry members can compete for the business of that now-realized customer. In fact, “most entrepreneurs will never be able to independently create a new market simply by building their companies” (Goldstein, 2004: B2). Brandenburger and Nalebuff (1996) advocate this strategy of both competing by stealing customers and cooperating by creating new customers, which they call *co-opetition*. We are interested in these simultaneous performance tradeoffs between spending on unrealized and realized customers. Specifically, we examine *how a new venture attempting to maximize profit should allocate marketing expenditures between investing to attract unrealized customers* (*which also increases total industry sales*)*, and investing to acquire realized customers* (*which only increases the new venture’s sales*).

Our research question is of importance because competing new ventures in nascent industries must build primary demand by attracting unrealized customers. Solely targeting the customers of a rival without marketing to new potential customers leads to a decrease in overall market size, because over time some existing customers will stop purchasing from either firm. In his discussion of the action pursuit games industry, Bernstein (2004) argues that “because communication has been focused almost exclusively on product sales, this ignores the fact that improving the environment for making sales IMPROVES [emphasis by the author] sales […] [U]ltimately, there won’t be a market unless all of us learn a little more about good PR” (p. 140). However, focusing solely on unrealized customers results in a new venture adding customers only to watch its rival steal them.

We use a game-theoretic framework that enables us to study new venture growth and competition over time and, as a result, to contribute to the interface of entrepreneurship and marketing research. Gilbert et al. (2006) point out that current research on new venture growth excludes the "*how* and *where* that growth is occurring." We examine these questions by investigating how new ventures should set optimal marketing expenditures to maximize their profit from sales growth. We also contribute by studying how changes in market conditions affect new venture growth and which type of new venture grows the fastest.

The marketing literature, conversely, has concentrated on models of firm competition which ignore unrealized customers or equate unrealized and realized customers. We expand upon that literature by demonstrating that the segmentation of unrealized and realized customers results in additional research insight. We also demonstrate that certain new venture capabilities, such as skill in attracting unrealized customers, may increase a rival's profit.

The remainder of this paper is organized as follows. In section §1.2 we review related literature in order to clarify our contributions. The model is described in §1.3, where expenditures on unrealized sales is modeled as a separate decision from expenditures on the rival's sales. In §1.4 we analytically derive optimal marketing expenditure strategies for competing new ventures in a single-period duopoly setting, whereas in §1.5 we use numerical and graphical methods to characterize these strategies in a multi-period differential game setting. Finally, §1.6 summarizes our results while offering managerial implications and extensions for future research.

1.2 Background Literature

Our literature review surveys previous findings on new venture growth (e.g., Delmar et al. 2003; Barringer et al., 2005; Gilbert et al., 2006) and marketing competition. In reviewing models with marketing expenditures as the decision variable, we highlight previous research on single-period models and continuous-time oligopoly settings (differential games as in, e.g., Wang and Wu, 2001; Erickson, 2003). We also examine previous research on customer segmentation (e.g., Fruchter and Zhang, 2004; Hartl and Kort, 2005; Bass et al., 2005a, 2005b) and spillover benefits (e.g., Krishnamurthy, 2000; Krishnamurthy et al., 2003) and explain how our model contributes to that modeling literature. Further, we highlight our research contributions at the interface of entrepreneurship and marketing.

Rapid adaptation to market changes is a vital success factor for new ventures in dynamic industries (e.g., Andren et al., 2003). However, new venture growth literature has mostly ignored the question of *how* new ventures grow in favor of focusing on *why* new ventures grow (Gilbert et al., 2006). In our decision framework, new ventures grow by allocating optimal marketing expenditures based on their capabilities (e.g., effectiveness in attracting unrealized customers), market share, and market size. This approach is supported by the findings of Barringer et al. (2005) on new venture attributes and Baum et al. (2001) on new venture competitive strategies as direct predictors of growth.

To further our understanding of *how* new ventures grow, Gilbert et al. (2006) suggest that researchers analyze models where the new venture can choose between internal growth (organic, due to product development or marketing ability to target unrealized customers) and external growth (acquisition, due to buying other firms). Our proposed game fits their suggested extension and enables us to compare our findings with some of their speculations. Delmar et al. (2003) identified several profiles of high-growth new ventures, which we use to compare new ventures in the multi-period model. Mullins' (1996) empirical study of hardware stores found that entrepreneurs with a high level of competence and good prior performance tend to react more slowly to opportunities for growth. We investigate if this "fat cat" phenomenon results from our model.

Modeling efforts in the marketing literature have largely represented advertising activities by one decision variable that impacts all targeted sales equally. We first review the single-period and discrete-time literature. Friedman (1958) offers models for a two player game in which players decide how to allocate their advertising budget over sales regions. There are no unrealized sales in this model. Similarly, Monahan (1987) considers the effectiveness of advertising and gross profit margins in competition for realized sales. In this framework, the advertising allocation decision is made by two players in multiple independent markets, but the size of the total market is still fixed. We only examine the market for one product, but unrealized sales may increase the total number of sales in the industry.

Shakun (1965) allows both market share and total market size to change as a function of firm advertising effort, but has no time dimension. Basuroy and Nguyen (1998) look at multiple firms that choose both advertising expenditures and product prices. They also consider the case of market entry, which we do not. They report that firms raise marketing expenditures and lower prices when the market is not fixed, whereas firms lower both marketing expenditures and prices when the market is fixed. However, Basuroy does not segment expenditures or effectiveness according to customer segment. Monahan and Sobel (1994, 1997) use discrete-period market-share games while exploring advertising decisions for multiple players. They extend their findings to stochastic and risk-sensitive conditions, which we do not, but do not consider unrealized sales.

Most models in the field tend to study advertising decisions in continuous time. For instance, the Lanchester model (Kimball, 1957) assumes that a firm acquires competitors' sales units via its advertising expenditures and loses its sales units via competitors' advertising expenditures. Most Lanchester models consider industry sales to be of fixed size. In contrast, Vidale and Wolfe (1957) examine a situation in which there are unrealized customers, resulting in variable industry sales. They model a monopolist who attracts unrealized customers via advertising expenditures, but who loses realized customers over time as the effects of advertising expenditures on customers wane.

Scholars have combined the concepts of the Lanchester and Vidale-Wolfe advertising models to relax the limitations of each. The Vidale-Wolfe model is augmented by Sethi (1973), who expands the modeling of a monopoly, and by Deal (1979), who includes competition in a duopoly. Some of the more recent combinations of the two models include Fruchter (1999), who adds market growth to a Lanchester model, and Wang and Wu (2001), who include market decay and growth in a Lanchester formulation. Fruchter (1999) points out that her oligopoly model would be more accurate if it would specify the difference in effectiveness between acquiring a rival's customers and attracting unrealized customers. We implement this difference in efficiency and thus can study marketing competition by modeling unrealized customers as well as customers already in the industry. Furthermore, our decision framework indicates that a rival's advertising can benefit a new venture by bringing more customers to the industry. To this end, we set advertising expenditure as the decision variable rather than sales level. This approach finds support in the work of Miller and Pazgal (2007).

Recently, there has been increased interest in customer segmentation in the differential game literature using different variables to represent expenditures on retaining customers, acquiring realized customers, and attracting unrealized customers. Working from a fixed industry sales framework, Fruchter and Zhang (2004) model expenditures on retaining and acquiring customers for multiple firms, whereas Hartl and Kort (2005) model expenditures on retaining and attracting customers in a single firm context. The multi-period duopoly model that most closely resembles ours is that of Bass et al. (2005a, 2005b), which models brand and generic advertising for two firms in an infinite and finite horizon context, respectively. The generic advertising of one firm directly benefits the other, just as if that second firm had done the advertising.

However, the Bass et al. model (2005a, 2005b) assumes that market size expands limitlessly with generic advertising and thus that industry sales are non-decreasing over time (although their infinite horizon model does have a market ceiling). Our decision model includes a market ceiling and sales decay in a finite horizon context, and we treat retention only in passing since we focus on nascent industries. In addition, for a nascent industry in which most unrealized customers have limited (if any) information about the product and new firms, the generic advertising of one new venture is unlikely to have a similar positive impact on the sales of its rival. We thus differ from Bass et al. (2005a, 2005b) in our contention that expenditures on unrealized customers may provide only indirect spillover benefits.

Wrather and Yu (1979) directly model spillover benefits in an oligopoly setting where firms maximize sales. In their framework, a firm can invest in product expenditures (which have spillover benefits to a rival firm) or brand expenditures (which acquire the sales of a rival firm). Wrather and Yu (1979) derive equilibrium points and discuss incentives for cooperation. In a multi-period, discrete-time oligopoly game, Friedman (1983) models the simultaneous decisions of multiple firms on quantity sold and advertising level. The cooperative (or predatory) nature of advertising is determined by one parameter for all firms and is unaffected by advertising expenditures or time. Also, Friedman (1983) does not distinguish between unrealized and realized sales. By contrast, in Krishnamurthy's (2000) single-period game, firms choose generic advertising (which expands the market) and brand advertising (which increases market share). He assumes that generic advertising is cooperative and focuses on when cheap-riding (under-investment in generic advertising by one firm) occurs. Krishnamurthy et al. (2003) argue that cooperative generic advertising is limited to industries subject to government regulation or those experiencing sales decline. Since neither condition is likely for a nascent industry, our model does not incorporate explicit cooperation (spillover) in marketing expenditures. This further differentiates our model from those of Krishnamurthy (2000) or Bass et al. (2005a, 2005b).

Our modeling contribution to the marketing literature is thus threefold. First, we represent the competitive elements of the Lanchester model and the market growth and decay elements of the Vidale-Wolfe model. To our knowledge, no other work has yet done so, and we find that all components have a strong effect on expenditure policies and profit. Second, we separate the rival's realized customers from the unrealized customers.

The one-variable modeling approach assumes that expenditures aimed at acquiring a rival's customers have the same impact on unrealized customers, and vice versa. This assumption is likely proven false in nascent industries because new ventures must inform unrealized customers of their offerings (Dorf and Byers, 2005) and convince them of their legitimacy (Aldrich and Fiol, 1994). Third, realized customers are typically early adopters and innovators with different characteristics from unrealized customers (Moore, 2000). We therefore segment customers and marketing efforts, as in Wrather and Yu (1979) and Bass et al. (2005a, 2005b), which necessitates the use of two variables for distinct expenditures on each segment.

Furthermore, we contribute to our understanding of the marketing-entrepreneurship interface. Our focus on new venture marketing activity is validated by Fock and Allampalli (2001), who support marketing as a key success factor for entrepreneurs in Singapore, and by Gundry and Kickul (2006), who argue that product innovations can lead to better market effectiveness and sales growth for e-commerce ventures. Morris et al. (2002) mention the unanswered question of whether optimal levels of entrepreneurial marketing exist, and if so, what influences those optimal levels. We next describe a decision model that addresses this question.

1.3 Optimal Marketing Strategy Model

Before introducing the mathematical decision model, we motivate its framework from the perspective of the entrepreneur managing the new venture. The entrepreneur must decide how much to spend on unrealized sales and on the realized sales of a rival new venture. The entrepreneur's goal is profit maximization, but she may also value the sales level reached by the end of the planning horizon, especially if the industry's customers are reluctant to switch firms. Suboptimal spending toward these goals can lead to slow sales growth, inability to expand out of a market niche, or poor performance compared to a rival's sales total as overall industry sales increase. The entrepreneur makes her decision based on factors such as past new venture effectiveness in marketing to unrealized and realized customers, the profit margin on each sales unit, and how many unrealized and realized sales exist.

We thus construct a mathematical decision model to enable that entrepreneur to understand the tradeoffs associated with this important decision. This model can provide practical guidance to entrepreneurs making a one-time decision on marketing expenditures, such as buying ads to support a marketing campaign or setting a budget. But this model will also benefit entrepreneurs who are fine-tuning marketing expenditures over time, such as making short-term assignments of sales people and ad content to different customer segments. Finally, since entrepreneurs must adjust their marketing expenditures as the market or the new firms change, a new venture's optimal response to such changes is investigated.

1.3.1 Decision Variables

Let t represent continuous time and T be the length of the planning horizon. New venture i invests in acquiring the sales of a rival new venture j at a marketing cost of $a_i(t)$; this investment is in *expenditures on a rival's sales*. Note that our model measures sales units rather than customers, as some customers may purchase more than one sales unit. When referring to human actions, we naturally describe aggregate sales units as customers. Symmetrically, new venture *i* invests in attracting unrealized customers at a marketing cost of $w_i(t)$. This investment is in *expenditures on unrealized sales* and can also be considered the new venture's investment in accelerating product diffusion. Thus, at any time *t*, new venture *i* is simultaneously investing in attracting unrealized sales via $w_i(t)$ and investing in acquiring its rival's sales via $a_i(t)$. Note that those marketing expenditures that do not specifically target either segment could be split proportionally (with the proportion based on historical data or surveys of targeted customers) between the segments.

1.3.2 Law of Motion for Sales

We focus on a duopoly of new firms *i* and *j*, which we also call *the new venture* and *its rival*, respectively. Let $S_i(t)$ be the number of units sold by new venture *i* at time *t*, and $S_j(t)$ be that of new venture *j*. Hence, $I(t) = S_i(t) + S_j(t)$ measures industry sales at time *t*. We are inspired by the Lanchester model (Kimball, 1957) and Vidale and Wolfe (1957) for our formulation of the law of motion for $S_i(t)$. The share of realized industry sales held by each new venture varies over time as a result of expenditures on its rival's sales $a_i(t)$. If the new venture is capable of implementing more complex marketing strategies, it will be more effective in acquiring sales (Gundry and Kickul, 2006). Thus, the efficacy of those expenditures depends on the new venture's ability as well as product and market conditions.

We denote the new venture's effectiveness in acquiring its rival's sales as a constant $\rho_i \in (0,1)$. New venture *i*'s expenditures on its rival's sales have an impact of value $\rho_i f_i(a_i(t))$ on acquiring the sales of new venture *j*. The function $f_i(a_i(t))$ is positive and increasing in its argument. Each dollar spent on the rival's sales via $f_i(a_i(t))$ yields a ρ_i fraction of the rival venture's realized sales. Similarly, new venture *j* acquires new venture *i*'s sales according to $\rho_j f_j(a_j(t))$. These combined effects on new venture *i*'s sales are

$$\rho_i f_i(a_i(t))S_j(t) - \rho_j f_j(a_j(t))S_i(t). \tag{1.1}$$

Industry sales reach market saturation as new firms build primary demand. Let *m* be the fixed number of units at which the market saturates, which corresponds to the maximum possible sales for the industry. The assumption that the market ceiling can be known is also used by Deal (1979), Fruchter (1999), and Wang and Wu (2001). Industry growth can only occur by attracting unrealized sales units, specifically $m - I(t)$ such units. A new venture's attraction of unrealized sales depends on the impact of its expenditures, as in the Vidale-Wolfe model (1957). New venture *i*'s effectiveness in attracting unrealized sales is denoted as a constant $\beta_i \in (0,1)$, and its expenditure has an impact of value $\beta_i g_i(w_i(t))$ on attracting unrealized sales units. The function $g_i(w_i(t))$ is positive and increasing in its argument.

There are also non-expenditure-related factors that affect sales. Let $[1-\delta_i] \in [0,1]$ be the sales decay parameter for new venture *i*. This parameter represents the proportion of sales units that depart the new venture (i.e., become unrealized) due to factors such as forgetfulness or product and market characteristics. Following Vidale and Wolfe (1957), it can also be interpreted as the constant proportion of existing sales units lost over time as market expenditure effects on existing customers wane and non-expenditure effects dominate. These combined effects on new venture *i*'s sales are

$$[\beta_i g_i(w_i(t)) + \theta_j \beta_j g_j(w_j(t))][m - S_i(t) - S_j(t)] - [1-\delta_i]S_i(t)\,. \tag{1.2}$$

By combining Equations (1.1) and (1.2), the change in new venture *i*'s sales over time can be expressed as

$$\begin{aligned}\dot{S}_i(t) = \rho_i f_i(a_i(t))S_j(t) - \rho_j f_j(a_j(t))S_i(t) \\ + \beta_i g_i(w_i(t))[m - S_i(t) - S_j(t)] - [1-\delta_i]S_i(t)\end{aligned}\,. \tag{1.3}$$

The four terms in (1.3) are, respectively, the gains in sales units acquired from competition, losses in sales units due to competition, gains in sales units due to the entry of unrealized sales units into the industry, and losses in sales units due to non-expenditure sales decay effects as previously realized customers decide to stop purchasing from either firm. We note that $f(\cdot)$ and $g(\cdot)$ can be chosen so that (1.1) is the Lanchester equation for existing sale competition, and (1.2) the Vidale-Wolfe equation for sales growth and decay.[1]

1.3.3 Objective Function

Let π_i be new venture *i*'s unit profit margin assumed fixed over time. Following the lead of Deal (1979), new venture *i*'s objective is to select on the finite horizon [0,*T*] a stream of expenditures on both unrealized sales and on the rival's sales that maximize its profit (net of advertising costs), plus a valuation of its end-of-horizon sales. Formally,

$$P_i = \underset{\substack{a_i(t),w_i(t)\\ t\in[0,T]}}{\text{Max}} \int_0^T [\pi_i S_i(t) - a_i(t) - w_i(t)]dt + r_i S_i(T)\,, \tag{1.4}$$

in which r_i is the salvage value that new venture *i* places on end-of-horizon sales. Relatively large salvage values r_i correspond to the new venture emphasizing end-of-horizon sales over profit. Similar to Wang and Wu (2001), we do not include a discount factor because we are interested in the nascent period of the industry and, as a result, *T* is relatively small. Omitting a discount factor also enables us to better compare expenditure amounts over time.

The complete optimal control formulation for new venture *i* includes Equations (1.3), (1.4), and the following conditions. Initial sales are set to a constant $S_i(0) = S_i^0$, whereas end-of-horizon sales $S_i(T)$ are not required to meet a pre-set level (similarly for the rival by symmetry). The decision variables are assumed to be nonnegative with $a_i(t) \in [0, \infty)$ and $w_i(t) \in [0, \infty)$. We discuss how $S_i(t)$, $S_j(t)$, and $m - S_i(t) - S_j(t)$ are kept nonnegative as we solve the single-period model.

1.4 Single-Period Analysis

In this section, we characterize optimal spending when two new firms make a one-time expenditure decision. We investigate the single-period model for two reasons. First, it enables us to model one-time decisions such as the annual budget or a one-time investment in an ad campaign. Second, the solutions for the single-period model require less information than those of the multi-period model, making this model more useful for practical decision-making. The solutions of a multi-period game (including ours) require knowledge of the other new venture's levels of expenditure effectiveness and sales decay. Hence, empirical verifications (e.g., as in Erickson, 1992 and Wang and Wu, 2001) have tended to focus on mature commodity oligopolies (e.g., Anheuser Busch vs. Miller, Coke vs. Pepsi) with a well-known advertising history.

As a special case of Equation (1.4), we solve for optimal expenditures in a single-period context with no salvage value (see appendix for further details). We select exponent functions (as, e.g., Erickson, 1985) to further our analysis. These functions are desirable because by varying the value of the exponent it is possible to “swipe” an infinite set of possible curves, making it easier to transform our theoretical model into an empirically testable framework. Thus,

$$f_i(a_i) = a_i^{1-\gamma_i} \text{ and } g_i(w_i) = w_i^{1-\theta_i}, \tag{1.5}$$

where γ_i, $\theta_i \in (0,1)$ represent the elasticity of the new venture’s expenditures in acquiring the rival’s sales and in attracting unrealized customers, respectively. The relationship between elasticity and effectiveness is that elasticity measures the new venture’s operational ability, whereas effectiveness measures its marketing ability. In other words, elasticity measures how much of the new venture’s investment is directly applied to realized and unrealized sales, and effectiveness measures how many acquired realized sales and attracted unrealized sales are added due to that directly applied investment. Substituting Equation (1.5) into the single-period model results in an optimal expenditure allocation on the rival’s sales and on unrealized sales units of

$$a_i^* = \left[\pi_i \rho_i S_j^0 [1-\gamma_i]\right]^{\frac{1}{\gamma_i}} \text{ and } w_i^* = \left[\pi_i \beta_i [m - S_i^0 - S_j^0][1-\theta_i]\right]^{\frac{1}{\theta_i}}. \tag{1.6}$$

Note that the only characteristic of the rival that affects the new venture’s optimal marketing expenditures is initial sales level. Thus, the new venture’s optimal expenditures have no effect on its rival’s optimal expenditures. We further analyze how the optimal marketing expenditures are affected by changes in new venture and market characteristics. Table 1.1 summarizes this sensitivity analysis. Results are obtained by taking the partial derivatives of the optimal expenditure variables in Equation (1.6) with respect to each parameter and holding the other parameters constant. Conditions for concavity are sufficient to derive the results in Table 1.1.[2]

Table 1.1 Sensitivity Analysis for the Single-Period Model

Increases in		The New Venture				Its Rival			
Description	Notation	Optimal expenditures on the rival's sales a_i^*	Optimal expenditures on unrealized sales w_i^*	End-of-period sales S_i	Profit P_i	Optimal expenditures on the new venture's sales a_j^*	Optimal expenditures on unrealized sales w_j^*	End-of-period sales S_j	Profit P_j
Effectiveness in attracting unrealized sales	β_i	–	↑	↑	↑	–	–	–	–
Effectiveness in acquiring the rival's sales	ρ_i	↑	–	↑	↑	–	–	↓	↓
Sales decay	$1-\delta_i$	–	-	↓	↓	–	–	–	–
Unit profit margin	π_i	↑	↑	↑	NM	–	–	↓	↓
Initial sales level	S_i^0	–	↓	NM	NM	↑	↓	NM	NM

Key: ↑ for increase, ↓ for decrease, – for unchanged, NM for non-monotonic

We first consider how improvements in the new venture's ability to add sales (either type) and sales decay affect performance, and conclude by exploring the impact of profit margin and initial sales levels.[3]

Results for effectiveness in attracting unrealized sales (β_i). An increase in β_i should increase the new venture's total expenditures, end-of-period sales, and profit. In contrast to the model of Krishnamurthy (2000), the rival does not increase profit because expenditures on unrealized sales are not cooperatively spent.

Results for effectiveness in acquiring the rival's sales (ρ_i). An increase in ρ_i due to an improvement in the new venture's product or advertising ability should lead to increased spending on the rival's sales units. This unconditional finding is in opposition to Monahan's model (1987), in which a firm's market share depends on the ratio of its advertising impact to the total advertising impact for all firms. Because his model had no unrealized sales, he found that a firm may decrease expenditures if it possesses a higher unit profit margin or effectiveness in acquiring realized sales than its rival. Furthermore, an increase in ρ_i boosts the new venture's end-of-period sales and profit. An increase in ρ_i will not affect the rival's expenditures; however, the rival's profit and end-of-period sales decrease. These findings on new venture profit complement those of Krishnamurthy (2000).

Results for sales decay ($1-\delta_i$). An increase in $(1-\delta_i)$ does not affect the new venture's total expenditures or those of its rival, but it does indicate that the new venture is retaining fewer realized sales and is losing both end-of-period sales and profit (although its rival's end-of-period sales and profit are unchanged). This finding is striking: new ventures should either spend more to offset the effects of sales decay or spend less because they cannot retain the sales they gain. We investigate this further in the multi-period setting.

Results for unit profit margin (π_i). An increase in π_i leads to the new venture spending more on both attracting unrealized sales and acquiring rival sales. This finding is supported in the single-period model of Monahan (1987). Since an increase in the new venture's total expenditures (not due to any sales losses) leads to higher end-of-period sales, one would also expect an increase in profit. However, Table 1.1 shows a non-monotonic relationship between π_i and profit. Further, its rival's profit and end-of-period sales decrease if the new venture obtains higher per-unit profit. Hence, if the new venture announces a production breakthrough that reduces costs (and increases unit profit margin), the rival should prepare for the new venture to increase its expenditures targeted at acquiring the rival's customers.

Results for initial sales level (S_i^0). If S_i^0 increases, the new venture should not change its spending on acquiring the rival's sales units, and should decrease spending on attracting unrealized sales. The decrease occurs because the pool of unrealized sales has grown smaller and, as a result, less is spent on pursuing those sales. If sales decay is low enough, the new venture may increase end-of-period sales and profit if its initial sales are high. Because this is a single-period model, the new venture may have an incentive to produce low initial sales levels if sales decay is high enough.

Unlike changes in the other four results, an increase in initial sales level for the new venture will affect the rival's expenditures. Specifically, the new venture's increase in initial sales results in the rival increasing expenditures on the now-increased number of new venture customers and decreasing expenditures on unrealized customers. The rival's re-balancing of its expenditure allocation may even increase end-of-period sales and profit. If both expenditure types have the same elasticity (i.e., $\gamma_j = \theta_j$ due to expenditure overlap in operational costs), two simple conditions govern whether the rival increases profit. If the rival is relatively more effective in acquiring new venture sales than in attracting unrealized sales ($\rho_j > \beta_j$), and new venture initial sales are more numerous than unrealized sales ($S_i^0 > m - S_i^0 - S_j^0$), then the rival should always increase total expenditures. Consequently, the rival's end-of-period sales and profit increase, and the new venture's increased initial sales have spilled over to benefit the rival.

Finally, note that an increase in new venture initial sales is more likely to increase the rival's profit if industry sales are relatively high ($S_i^0 + S_j^0 \approx m$), because new venture initial sales are more likely to outnumber unrealized sales ($S_i^0 > m - S_i^0 - S_j^0$). This observation shows that the new venture is less (more) likely to profit from sales growth of its rival when either that rival's sales or total industry sales are small (large, respectively). We next explore the robustness of some of these findings in a multi-period setting.

1.5 Multi-Period Analysis

We demonstrate in the appendix that the multi-period model cannot be solved in closed form. Consequently, a sensitivity analysis based solely on analytical derivations cannot be conducted to compare prescriptions between the multi-period and single-period settings. Instead, we employ numerical analysis to gain insight on how marketing expenditures, sales, and profit change over time. We use a solution algorithm that discretizes time using difference approximations and solves for the state variables using forward and backward passes (see Erickson [2003: pp. 61–62] for a complete explanation). A wide range of parameter values were tested with the solution algorithm.[4] The length of the planning horizon affects the end-of-horizon sales values. If an overly short finite horizon is selected, initial values dominate and expenditure decisions have little effect. However, an infinite horizon is unrealistic for our context of the industry's nascent period in which initial sales levels should have some impact on end-of-horizon sales and profit. We therefore selected a common planning horizon of T = 6 periods.[5]

To allow for ease of comparison to previous research (e.g. Wang and Wu 2001, Bass et al. 2005a, 2005b), we studied the case where the elasticity for all expenditures is equal to one-half ($\gamma_i = \gamma_j = \theta_i = \theta_j = 1/2$). We standardized the market ceiling m by setting it equal to 1. For ease of comparison with the work of Bass et al. (2005b), salvage values are set to zero ($r_i = r_j = 0$). Because financing is important for new ventures, we also record first-period earnings (profit from t = 0 to t = 1). Simpson's 1/3 Rule, a calculus technique for approximating a definite integral, is used to sum first-period earnings, profit, and expenditures.

A sampling of the results is offered in Table 1.2. In Runs 1–5, we study how both new firms should adjust expenditures in response to changes in ability to attract unrealized sales and acquire the rival's sales, sales decay, unit profit margin, and initial sales. We also measure how the performance (i.e., end-of-horizon sales and profit) of both new firms is affected. In the first half of each run the new venture is more effective at attracting unrealized sales than the rival, and the rival is more effective at acquiring realized sales than the new venture. In the second half, the new firms switch roles.

Table 1.2 Numerical Solutions

$$\left(m=1,\ r_i=r_j=0,\ \gamma_i=\gamma_j=\theta_i=\theta_j=1/2\right)$$

Parameter Values		Exp., Rival N.V. i	Exp., Rival N.V. j	Exp., Unrealized N.V. i	Exp., Unrealized N.V. j	Final Sales N.V. i	Final Sales N.V. j	First Period Profit N.V. i	First Period Profit N.V. j	Total Profit N.V. i	Total Profit N.V. j
	1. Eff. Unrealized Sales β_i , β_j										
$\rho_i=.01$ $\pi_i=300$	(a) .005, .005	$0.09	$0.73	$14.77	$15.25	.028	.030	$1.60	$1.50	$45.84	$47.85
$\rho_j=.03$ $\pi_j=300$	(b) .010, .005	0.09	2.81	49.13	14.20	.073	.032	-1.13	1.48	84.48	49.02
$S_i^0=.03$ $1-\delta_i=.20$	(c) .020, .005	0.11	13.39	118.97	11.56	.176	.047	-5.74	1.37	188.58	58.68
$S_j^0=.03$ $1-\delta_j=.20$	(d) .030, .005	0.16	27.72	161.24	9.27	.255	.071	-7.01	1.13	290.12	74.62
	(e) .040, .005	0.24	41.54	181.65	7.56	.311	.094	-6.00	0.82	376.98	91.74
$\rho_i=.03$ $\pi_i=300$	(f) .005, .005	0.73	0.09	15.25	14.77	.030	.028	1.50	1.60	47.85	45.84
$\rho_j=.01$ $\pi_j=300$	(g) .010, .005	0.71	0.37	52.37	13.75	.080	.027	-1.59	1.62	90.33	45.08
$S_i^0=.03$ $1-\delta_i=.20$	(h) .020, .005	0.67	2.08	134.04	11.18	.204	.026	-7.76	1.69	214.68	44.21
$S_j^0=.03$ $1-\delta_j=.20$	(i) .030, .005	0.67	4.87	187.19	8.99	.308	.027	-10.50	1.73	344.62	44.86
	(j) .040, .005	0.69	7.89	214.18	7.37	.385	.030	-10.34	1.74	459.48	46.37
Parameter Values	2. Eff. Rival Sales ρ_i , ρ_j										
$\beta_i=.03$ $\pi_i=300$	(a) .005, .005	$0.06	$1.24	185.43	$33.78	.300	.050	-$11.14	-$0.88	$338.18	$69.64
$\beta_j=.01$ $\pi_j=300$	(b) .010, .005	0.23	1.24	185.43	33.59	.301	.050	-11.14	-0.85	338.41	69.30
$S_i^0=.03$ $1-\delta_i=.20$	(c) .020, .005	0.87	1.23	185.43	32.87	.302	.049	-11.16	-0.73	339.28	67.99
$S_j^0=.03$ $1-\delta_j=.20$	(d) .030, .005	1.79	1.20	185.44	31.80	.303	.047	-11.18	-0.56	340.62	66.01
	(e) .040, .005	2.87	1.18	185.46	30.49	.305	.045	-11.21	-0.36	342.29	63.59
$\beta_i=.01$ $\pi_i=300$	(f) .005, .005	1.24	0.06	33.78	185.43	.050	.300	-0.88	-11.14	69.64	338.18
$\beta_j=.03$ $\pi_j=300$	(g) .010, .005	4.69	0.06	33.75	182.03	.056	.293	-0.95	-10.65	73.35	331.12
$S_i^0=.03$ $1-\delta_i=.20$	(h) .020, .005	15.34	0.07	33.69	170.73	.076	.271	-1.17	-9.05	85.93	307.81
$S_j^0=.03$ $1-\delta_j=.20$	(i) .030, .005	26.48	0.09	33.67	157.04	.098	.244	-1.38	-7.22	101.61	279.95
	(j) .040, .005	35.42	0.11	33.72	143.70	.118	.219	-1.53	-5.54	117.29	253.20
Parameter Values	3. Sales Decay 1-δ_i , 1-δ_j										
$\beta_i=.03$ $S_i^0=.03$	(a) .05, .05	$1.33	$54.58	$175.82	$47.73	.332	.217	-$12.15	-$5.48	$354.25	$177.26
$\beta_j=.01$ $S_j^0=.03$	(b) .10, .05	1.12	47.76	164.77	50.87	.288	.204	-9.90	-5.60	317.84	169.84
$\rho_i=.01$ $\pi_i=300$	(c) .15, .05	0.96	41.76	154.43	53.80	.251	.194	-8.04	-5.70	285.98	163.90
$\rho_j=.03$ $\pi_j=300$	(d) .20, .05	0.83	36.49	144.71	56.51	.219	.186	-6.49	-5.77	257.99	159.14
	(e) .25, .05	0.72	31.87	135.54	59.02	.193	.179	-5.20	-5.84	233.33	155.36
$\beta_i=.01$ $S_i^0=.03$	(f) .05, .05	54.58	1.33	47.73	175.82	.217	.332	-5.48	-12.15	177.26	354.25
$\beta_j=.03$ $S_j^0=.03$	(g) .10, .05	49.25	1.02	39.48	181.52	.176	.346	-3.63	-12.63	152.45	365.98
$\rho_i=.03$ $\pi_i=300$	(h) .15, .05	44.55	0.79	32.90	186.61	.145	.358	-2.25	-13.09	132.09	376.64
$\rho_j=.01$ $\pi_j=300$	(i) .20, .05	40.40	0.61	27.62	191.17	.120	.369	-1.21	-13.53	115.26	386.33
	(j) .25, .05	36.72	0.48	23.36	195.25	.100	.379	-0.43	-13.95	101.25	395.15
Parameter Values	4. Profit Per Unit Sold π_i , π_j										
$\beta_i=.03$ $S_i^0=.03$	(a) 100, 100	$0.01	$1.36	$36.74	$5.38	.163	.036	-$1.96	$0.40	$57.32	$17.51
$\beta_j=.01$ $S_j^0=.03$	(b) 200, 100	0.05	2.92	103.26	4.59	.240	.040	-5.69	0.40	173.72	18.38
$\rho_i=.01$ $1-\delta_i=.20$	(c) 300, 100	0.12	4.27	178.36	4.08	.289	.045	-9.35	0.39	325.29	19.34
$\rho_j=.03$ $1-\delta_j=.20$	(d) 400, 100	0.23	5.43	256.28	3.70	.324	.050	-12.51	0.38	501.48	20.26
	(e) 500, 100	0.38	6.43	334.87	3.41	.350	.053	-15.06	0.37	696.37	21.09
$\beta_i=.01$ $S_i^0=.03$	(f) 100, 100	1.36	0.01	5.38	36.74	.036	.163	0.40	-1.96	17.51	57.32
$\beta_j=.03$ $S_j^0=.03$	(g) 200, 100	4.70	0.02	20.35	34.55	.059	.151	-0.16	-1.77	48.04	53.89
$\rho_i=.03$ $1-\delta_i=.20$	(h) 300, 100	9.28	0.04	43.42	32.70	.080	.141	-1.48	-1.61	90.22	51.01
$\rho_j=.01$ $1-\delta_j=.20$	(i) 400, 100	14.66	0.05	73.42	31.10	.099	.133	-3.43	-1.47	142.97	48.54
	(j) 500, 100	20.56	0.07	109.38	29.69	.116	.126	-5.89	-1.35	205.40	46.38
Parameter Values	5. Initial Sales S_i^0 , S_j^0										
$\beta_i=.03$ $\pi_i=500$	(a) .00, .00	$3.45	$115.34	$288.45	$95.34	.301	.235	-$17.38	-$15.88	$578.60	$297.40
$\beta_j=.01$ $\pi_j=500$	(b) .02, .00	3.49	118.08	281.97	93.24	.301	.235	-13.59	-15.88	594.32	299.35
$\rho_i=.01$ $1-\delta_i=.05$	(c) .04, .00	3.54	120.93	275.58	91.15	.300	.236	-9.85	-15.92	609.80	301.59
$\rho_j=.03$ $1-\delta_j=.05$	(d) .06, .00	3.59	123.90	269.29	89.04	.300	.238	-6.16	-15.98	625.04	304.12
	(e) .08, .00	3.65	126.97	263.08	86.94	.300	.239	-2.51	-16.06	640.04	306.93
$\beta_i=.01$ $\pi_i=500$	(f) .00, .00	115.34	3.45	95.34	288.45	.235	.301	-15.88	-17.38	297.40	578.60
$\beta_j=.03$ $\pi_j=500$	(g) .02, .00	111.89	3.90	92.86	284.80	.238	.298	-12.03	-17.34	331.59	568.99
$\rho_i=.03$ $1-\delta_i=.05$	(h) .04, .00	108.48	4.40	90.41	281.10	.242	.295	-8.19	-17.30	365.77	559.38
$\rho_j=.01$ $1-\delta_j=.05$	(i) .06, .00	105.12	4.98	87.97	277.34	.246	.293	-4.36	-17.26	399.94	549.78
	(j) .08, .00	101.82	5.62	85.56	273.52	.250	.290	-0.55	-17.21	434.10	540.18

In the following discussion, we examine how the dynamic dimension changes some of the results from our single-period model and previous models in the literature. We also provide a graphical analysis of how rising sales decay influences new venture performance. Table 1.3 summarizes the conjectures derived from our numerical analysis. As we discuss our findings, we continue to refer to new venture *i* as *the new venture* and to new venture *j* as *its rival*.

Table 1.3 Conjectured Sensitivity Analysis for the Multi-Period Model

Increases in		The New Venture				Its Rival			
Description	Notation	Expenditures on the rival's sales $\int_0^T a_i^*(t)dt$	Expenditures on unrealized sales $\int_0^T w_i^*(t)dt$	End-of-horizon sales $S_i(T)$	Profit P_i	Expenditures on the new venture's sales $\int_0^T a_j^*(t)dt$	Expenditures on unrealized sales $\int_0^T w_j^*(t)dt$	End-of-horizon sales $S_j(T)$	Profit P_j
Effectiveness in attracting unrealized sales	β_i	NM	↑	↑	↑	↑	↓	NM	NM
Effectiveness in acquiring its rival's sales	ρ_i	↑	NM	↑	↑	NM	↓	↓	↓
Sales decay	$1-\delta_i$	↓	↓	↓	↓	↓	↑	NM	NM
Unit profit margin	π_i	↑	↑	↑	↑	NM	↓	NM	NM
Initial sales level	S_i^0	NM	↓	NM	↑	↑	↓	NM	NM

Key: ↑ for increase, ↓ for decrease, NM for non-monotonic

Results for effectiveness in attracting unrealized sales (β_i). As per Run 1 in Table 1.2, a new venture should react to an increase in β_i by increasing its expenditures on unrealized sales. This result was also confirmed by Bass et al. (2005b). However, in contrast to Bass et al. (2005a), we find that the new venture's expenditures on the rival's sales are affected when β_i increases. Also, in contrast to Wang and Wu (2001), our model indicates that the new venture should not decrease total expenditures. The rival responds by decreasing its expenditures on unrealized sales units and increasing its expenditures on the new venture's sales. The rival does so because the new venture is now increasing its sales by attracting more unrealized sales, and thus fewer unrealized sales are available for the rival.

These expenditure changes result in a sharp increase in the new venture's end-of-horizon sales and profit, even when facing a rival with superior ability to acquire realized sales (first half of Run 1). The rival's end-of-horizon sales and profit offer the most interesting results of Run 1. In the first half of Run 1, the new venture is less effective than its rival in acquiring realized sales (.030 to .010). As a result, the rival also benefits from the new venture's improved effectiveness in attracting unrealized sales, nearly doubling end-of-horizon sales and total profit from Run 1(a) to 1(e). The new venture should increase expenditures on the rival's sales because the rival's sales are increasing so quickly.

However, in the second half of Run 1, the new venture is better than the rival at acquiring realized sales and is also increasing its advantage in attracting unrealized sales. The rival suffers a decrease in end-of-horizon sales and profit from (f) to (g) and (g) to (h), but then improves its performance from (h) to (i) and (i) to (j). This causes the new venture to increase its expenditures on the rival's sales. In (i) and (j), the rival is now more competitive on realized sales (.01 to .03) and the new venture attracts even more unrealized sales (its effectiveness increases to .03 and .04, respectively). We argue that the rival has shifted its expenditure focus toward the new venture's sales, thereby increasing its sales and profit. We conclude that as the new venture's effectiveness in attracting unrealized customers increases, the resulting increase in total industry sales will eventually also improve the rival's performance.

Our numerical findings thus contradict those of Bass et al. (2005a), who find that a new venture's increased ability to attract unrealized sales has no effect on the rival's decisions and performance other than increasing the rival's profit, and that the new venture should not change its expenditures on the rival's sales. The difference in results exists because of our assumption that spillover benefits from spending on unrealized sales are *indirect*. We argue that our assumption is a better representation of new venture competition. After all, a new venture that improves its effectiveness in attracting unrealized customers should certainly experience an increase in sales, and a new venture's improved effectiveness in attracting unrealized sales should influence the rival in some way.

Therefore, we offer an altered recommendation from Bass et al. (2005a). When the new venture's effectiveness in attracting unrealized sales increases, the rival should not increase its expenditures on unrealized sales. Rather, it should re-balance its allocation of expenditures to spend more on the new venture's sales and less on unrealized sales. If the rival implements such a strategy, it may still increase end-of-horizon sales and profit despite the new venture's preferred status among unrealized customers. Similarly, the new venture should expect that its rival may follow this strategy. The new venture may need to increase its own expenditures on the rival's sales to mitigate the effects of the rival's increased spending.

Results for effectiveness in acquiring the rival's sales (ρ_i). As per Run 2, a new venture should react to an increase in ρ_i by increasing its expenditures on the rival's sales. If the new venture is also more effective in attracting unrealized sales than its rival, the new venture's expenditures on unrealized sales will increase slightly as ρ_i increases (first half of Run 2). We speculate that because the new venture is able to acquire the rival's sales more rapidly, it also invests a little more in unrealized sales. Otherwise, the expenditures on unrealized sales may increase (Run 2(h) to 2(i)) or decrease (Run 2(i) to 2(j)).

In response to the new venture's improved effectiveness in acquiring sales, the rival decreases its expenditures on unrealized sales. We thus argue that a new venture should be cautious about targeting the rival's sales, depending on the state of the new firms and industry. If both industry sales and rival sales are high, the new venture should target the rival's sales. However, if industry and rival sales are low, targeting the rival may decrease the number of unrealized customers flowing into the industry. Thus, the new venture must be much more cautious about targeting a rival's sales in a nascent industry than in a mature industry. However, unlike the result of Bass et al. (2005a), the rival may not decrease all expenditures; the second half of Run 2 provides a counter-example in which the rival slightly increases its expenditures on the new venture's sales. We speculate that the rival does so when it is more effective than the new venture in attracting unrealized sales, in an effort to regain some of the realized sales the new venture stole. Overall, however, the rival's expenditures on the new venture's sales appear to be minimally affected by changes in the new venture's ability to acquire the rival's sales. Thus, we hypothesize that advertising wars, in which both new firms sharply increase expenditures on realized sales, should be rare in a nascent industry.

The end-of-horizon sales and profit results are straightforward. The new venture improves its performance, while the rival suffers a loss in end-of-horizon sales and profit. In contrast to Bass et al. (2005a) and our result in the single-period model, we find no evidence that an increase in the new venture's effectiveness in acquiring the rival's sales would decrease the new venture's profit. We also compare first-period earnings when the new venture's effectiveness in acquiring the rival's sales (Run 2) or in attracting unrealized sales (Run 1) increases. The first-period profit decreases less rapidly in Run 2; an increase in effectiveness in acquiring the rival's sales has a negligible influence on first-period earnings and even increases the rival's first-period earnings. More specifically, the new venture and rival experience positive first-period earnings in Run 1(a) when effectiveness in attracting unrealized sales is low, but negative first-period earnings in Run 2(f) when effectiveness in attracting unrealized sales is higher for both new firms. We further analyze the relationship between first-period earnings and profit in §1.6.

Results for sales decay ($1-\delta_i$). As per Run 3, a new venture should react to an increase in ($1-\delta_i$) by decreasing expenditures on both unrealized sales and its rival's sales. This result is in opposition to Wang and Wu (2001), who argue for an increase in expenditures. Our rationale is that added sales become less valuable for the new venture as sales decay increases because retention of added sales decreases. Thus, the new venture spends less, resulting in fewer sales, and the rival reacts by decreasing expenditures on the new venture's sales. However, because the new venture is attracting fewer unrealized sales, the rival increases expenditures on unrealized sales and may increase total expenditures.

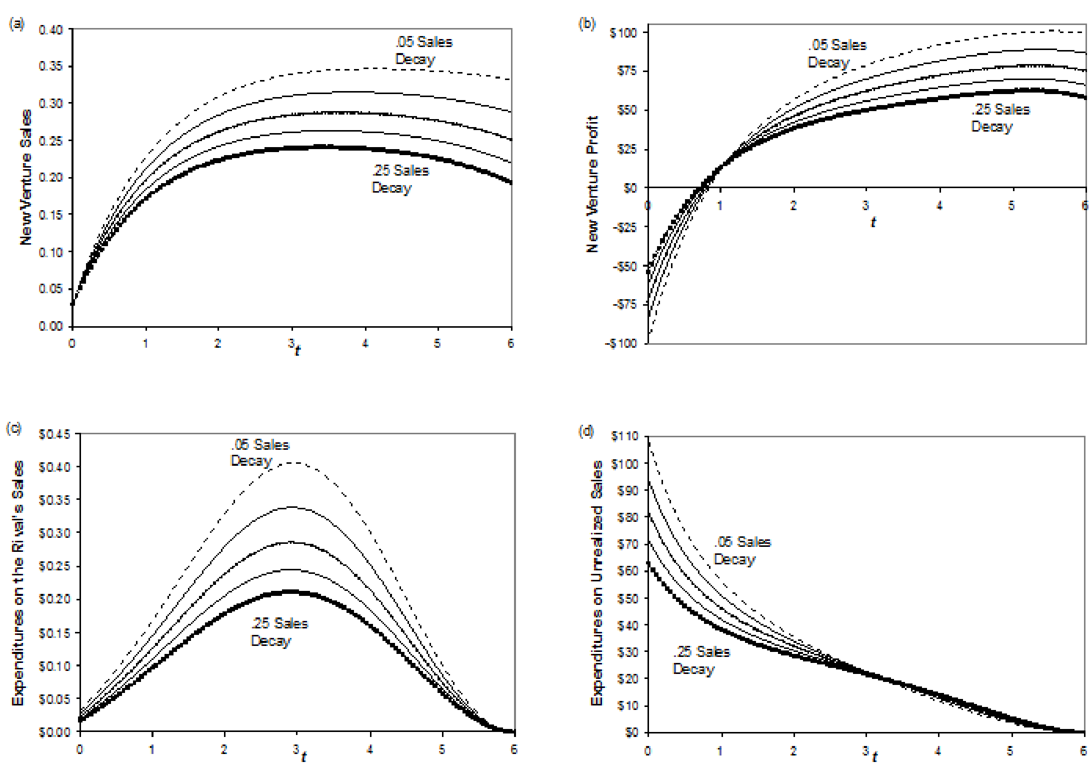
Just as in Deal (1979), an increase in sales decay decreases the new venture's total expenditures, end-of-horizon sales, and profit. However, in contrast to Deal (1979), who did not have separate effectiveness measures for unrealized and realized customers, higher sales decay for the new venture may decrease its rival's end-of-horizon sales and profit. We speculate that if the rival is more effective in acquiring the new venture's sales than in attracting unrealized sales (as in the first half of Run 3), increasing sales decay for the new venture will reduce both the number of its sales the rival can acquire and the rival's profit. Otherwise, in the second half of Run 3, in which the rival is more effective in attracting unrealized sales, the rival's profit increases as the new venture's sales decay becomes worse.

We give further insight as to how increases in sales decay affect new venture performance via graphical illustrations of sales, profit, and expenditures over time in Figure 1.1. These illustrations describe the first half of Run 3. As per Figure 1.1(a), low sales decay leads to higher sales at every time period. As per Figure 1.1(b), at first the new venture's reduction in expenditures saves money. However, after the first period, the reduced expenditures on unrealized sales harm its profit, and by $T = 6$ we confirm that the lowest sales decay corresponds to the highest profit and end-of-horizon sales. Expenditures on the rival's sales, as in Figure 1.1(c), keep the same curve shape, but decrease as sales decay increases. In our simulations, we commonly observed the inverted U-shaped curve when the rival increases sales, and frequently noted a monotonically decreasing convex curve when the new venture decreases sales or experiences slow sales growth.

For expenditures on unrealized sales, as per Figure 1.1(d), high sales decay lowers initial spending. However, after t = 3, the reverse is true: the higher the sales decay, the higher the expenditures on unrealized sales. We speculate that this relationship occurs because the new venture is using expenditures on unrealized sales to replace sales lost due to high sales decay, rather than to increase overall sales. Our conjecture is supported by Figure 1.1(a), in which new venture sales decrease after t = 3. Thus, we are able to show that expenditures on unrealized sales, besides being used to rapidly increase industry sales, may also function to help stabilize the new venture's sales level by replacing realized customers that have departed the industry.

Figure 1.1 Sales, Profit, and Expenditures for the New Venture (first part of Run 3 in Table 1.2)

$$\beta_i = .03, \beta_j = .01, \rho_i = .01, \rho_j = .03, S_i^0 = .03, S_j^0 = .03, \pi_i = 300, \pi_j = 300$$



Results for unit profit margin (π_i). As per Run 4, a new venture reacts to an increase in π_i by increasing expenditures on unrealized sales and its rival's sales — a result that complements that of Wang and Wu (2001). We were able to construct a few runs (not shown) in which the rival decreased its expenditures on the new venture's sales, as in Bass et al. (2005a). However, Run 4 represents the more typical rival reaction with increased expenditures on the new venture's sales and decreased expenditures on unrealized sales. Total rival expenditures will increase or decrease depending on whether the rival is more effective in acquiring the new venture's sales or attracting unrealized sales. Arguably, the rival's reactions could occur because the new venture's increased spending on the rival's sales reduces the rival's sales return from expenditures on unrealized sales. At the same time the new venture's increased spending on unrealized sales increases the rival's sales return from expenditures on the new venture's realized sales.

In contrast to our single-period model, an increase in π_i never decreases the new venture's profit. The new venture always improves both end-of-horizon sales and profit. The rationale may be that when there is a carryover effect in sales (i.e., more than a one-time decision), the new venture can always increase its profit if its unit profit margin is larger. Surprisingly, in contrast to our single-period model, an increase in the new venture's unit profit margin may increase the rival's end-of-horizon sales and profit. The rationale is that during multiple periods when the rival possesses high effectiveness in acquiring the new venture's sales (as in the first half of Run 4), the rival eventually benefits from the new venture's increase in unrealized sales.

Our numerical findings for the rival thus contrast with those of Bass et al. (2005a), in which a new venture's increase in unit profit margin decreases the rival's expenditures on the new venture's realized sales and steady-state market share. Accordingly, we offer an altered recommendation. When the new venture's unit profit margin increases, its rival should generally react by increasing expenditures on the new venture's realized sales rather than cutting expenses altogether as in the Bass et al. model (2005a). That higher unit profit margin for the new venture results in higher end-of-horizon sales. Thus, if the rival increases expenditures on the new venture's sales, it may acquire enough of the new venture's newly realized sales to increase end-of-horizon sales and profit despite the new venture's increased expenditures on the rival's sales.

Lastly, when unit profit margin increases in Run 4, first-period earnings tend to decrease and profit increases. For further analysis, we focus on Run 4(a), where both new firms have the same unit profit margin. If the new venture is skilled in acquiring realized customers, then its first-period earnings are positive. But if it is skilled at attracting unrealized customers, then it absorbs negative first-period earnings. Therefore, initially, the new venture that specializes in targeting its rival appears to be less likely than its rival to face negative earnings. However, in the long term that new venture is less profitable than if it had been more effective in attracting unrealized customers. We also note that if the new venture is highly effective in attracting unrealized sales, it will experience the double benefit of increased first-period earnings and profit (e.g., in Run 1 when effectiveness in attracting unrealized sales increases from .030 to .040).

Results for initial sales (S_i^0). As per Run 5, the new venture should react to an increase in S_i^0 by decreasing expenditures on unrealized sales, because growth in the new venture's initial sales indicates a lower number of remaining unrealized sales. Similar reasoning applies to the rival: it should react to an increase in the new venture's initial sales by increasing its expenditures on the now more-numerous new venture sales and decreasing its expenditures on the now less-numerous unrealized sales.

However, the new venture's expenditures on the rival's sales have a non-monotonic relationship with increased initial sales. Intuition would indicate that if a new venture is more effective at adding rival's sales than unrealized sales and its initial sales increase, it should increase expenditures on its rival's sales. Nevertheless, the opposite occurs. In the first half of Run 5, the new venture's effectiveness in acquiring realized sales is low, but its effectiveness in attracting unrealized sales (.03 to the rival's .01) leads to higher sales when its initial sales increase. Because the rival is skilled in acquiring the new venture's sales, it acquires even more of that new venture's sales. Consequently, the new venture must increase expenditures on its rival's sales.

Conversely, when the new venture is instead highly effective in acquiring the rival's sales (second half of Run 5), the new venture lowers expenditures on its rival's sales as its initial sales increase. The explanation is that as the new venture's initial sales increase, the unrealized sales decrease. Because the rival has high effectiveness in attracting unrealized sales, it cannot grow rapidly. As a result, the new venture decreases expenditures on the rival's sales. Note that for the second half of Run 5, the new venture increases sales and profit while the rival decreases sales and profit.

In Run 5, we chose a relatively higher unit profit margin and lower sales decay to showcase a surprising result. When the new venture's initial sales increase, it may actually reduce the new venture's end-of-horizon sales while increasing its rival's end-of-horizon sales and profit. The first half of Run 5 shows this result, which occurs if the rival possesses a large enough advantage in acquiring realized sales (.03 to .01). The rival targets the new venture's higher initial sales successfully and increases its own sales and profit at the expense of that new venture's large initial sales base. This confirms our single-period result that if a new venture's sales are large enough, the rival will increase profit. However, in contrast to our single-period model, the multiple-period framework never finds that a new venture decreases profit from an increase in initial sales. We thus argue that because a new venture with more initial sales earns more profit at the beginning of the planning horizon, total profit increases even if it cannot retain those extra initial sales over time.

1.6 Conclusions

This research complements existing marketing research by synthesizing the Lanchester (inspired by Kimball, 1957) and Vidale-Wolfe (1957) models to show how new firms should allocate marketing expenditures between acquiring a rival's customers and attracting unrealized customers. We summarize our findings by presenting them as prescriptions to be used by entrepreneurs in nascent industries (i.e., new venture managers) and financers of those new firms. By highlighting some of the tradeoffs between focusing on unrealized customers and those of the rival, we can better position these findings with respect to previous research on new venture growth.

In a setting where an entrepreneur must make a one-time expenditure decision (e.g., yearly budgeting), we show that a new venture should react to improvements in its ability to attract unrealized customers and acquire the customers of its rival by increasing expenditures. Furthermore, if a new venture is most effective at acquiring the rival's customers and there are enough of those customers relative to unrealized customers, that new venture's performance can be improved when the rival increases initial sales. Therefore, even in a single-period setting, spillover benefits from the rival's sales may increase the new venture's profit. We also note that only an increase in the new venture's effectiveness in acquiring its rival's customers is certain to lead to higher profit for the new venture but lower profit for its rival.

Our numerical analysis for the multi-period model provides guidance for new firms when either one improves its capability. This improvement may correspond to an increase in effectiveness in acquiring realized customers or attracting unrealized customers, lower sales decay, improved unit profit margin, or an increase in initial sales level. Because any improvement in the new venture's capability increases its profit, the most interesting prescriptions arise when improvements in the rival's capability affect the new venture's profitability. Such is the case when the new venture is highly effective in acquiring the rival's customers and increases its expenditures to steal those customers.

However, because a new venture's improvement can benefit its rival, our research also suggests that new firms should not be overly aggressive when the rival struggles. If a rival experiences increased customer losses due to poor product quality, we recommend that the new venture increase spending to bring unrealized customers into the industry rather than increase marketing expenditures to target its rival's customers. Such an action will help slow the overall reduction in industry sales due to the rival's departing customers.

Even if the new venture manager follows our recommendation, the firm may still lose customers and profit due to the rival's increased sales decay. We thus suggest that new venture managers take all appropriate measures, even to the point of collaboration with a rival, to slow down or reverse sales decay trends in the industry. This complements Bernstein's (2004) recommendation as outlined in our introduction. Because sales decay may weaken performance for both firms, rivals may be willing to collaborate.

Further, a manager should pay close attention to unrealized customers at the beginning of the nascent industry when industry sales are low and be less concerned about the rival's customers. The new venture with the greater effectiveness in reaching unrealized customers tends to be the most profitable, provided that it is not too far behind its rival in other capabilities. However, if the manager of a rival is an expert in attracting unrealized customers and the new venture manager is a novice at acquiring customers from that rival, the latter will likely experience decreased profit over time. If industry sales increase, the new venture's manager should increase expenditures that target rival customers and gradually reduce expenditures on unrealized customers. MSN and other ISPs successfully took this step against AOL as the nascent Internet service provider industry grew.

Our multi-period analysis affirms previous research on new venture growth by Mullins (1996), Delmar et al. (2003), and Gilbert et al. (2006). First, we found that a new venture with high initial sales (i.e., good prior performance) coupled with higher effectiveness in attracting unrealized sales (i.e., high level of competence) may still lose sales to its rival and only marginally increase profit. This finding provides support for the “fat cat” phenomenon noted by Mullins (1996), in which firms with good prior performance and a high level of competence tended to be slow in seizing growth opportunities.

Second, the effectiveness levels of the new firms were matched to the profiles of high-growth new ventures reported by Delmar et al (2003). Specifically, in the first half of each run in Table 1.2, the new venture fit the *steady overall grower* profile (skilled in attracting unrealized sales) and the rival fit the *acquisition grower* profile (skilled in acquiring rival sales) as two types of high-growth new firms. In Table 1.2, whenever the new venture fits the profile of the steady overall grower, it always earned higher sales and profit. Therefore, in nascent industries where the initial sales level is low, a new venture should earn a higher profit if it is managed as a steady overall grower rather than an acquisition grower.

Third, we speculate that a steady overall grower should sharply increase sales (but gradually increase market share), and an acquisition grower should sharply increase both sales and market share. We note that the steady overall grower rapidly attracts more sales to the industry, which enables the acquisition grower to acquire more customers. Consequently, our findings for the steady overall grower complement the theory of Gilbert et al. (2006). However, as reported above, an acquisition grower typically has less market share and sales than the steady overall grower, given the same opportunity. Our findings for the acquisition grower are thus in contrast with the more optimistic speculation of Gilbert et al. (2006).

Those investing in new ventures, including venture capitalists and business angels, may benefit from exercising patience with new ventures in nascent industries that show favorable growth potential (e.g., high effectiveness in attracting unrealized customers, low sales decay, or high profit margin). Although our numerical analysis shows that initial profit in such industries tends to be lower than in nascent industries with less favorable growth potential, the new venture becomes highly profitable with the passing of time. Moreover, financers can assist new ventures in setting their sales focus and strategy. New ventures with high effectiveness in attracting unrealized customers tend to be more profitable than those with high effectiveness in acquiring the customers of their rivals. Financers should therefore advise new venture managers to take actions and add resources that will improve their ability to attract new customers. Over the long term, such a strategy will lead to higher sales and profit.

However, we caution that judging from first-period profit, a new venture that excels in acquiring a rival's customers may initially require less financing than if it excels in attracting unrealized customers. Financers who push a new venture to focus on unrealized customers must guarantee that the new venture has adequate funds to support this strategy. If funds are lacking, the new venture managers should be advised instead to focus on improving effectiveness in targeting the rival's customers — a policy that is initially less expensive, yet dependent on the rival's ability to attract unrealized customers.

We could further contribute to the new venture growth literature by introducing a first-stage decision in which the new firms also spend to improve their capabilities. Specifically, prior to investing in an ad campaign, a new venture could hire extra salespeople to increase its effectiveness in attracting unrealized customers. Our decision model could be extended to explore optimal budget allocation between improving capabilities and investing in marketing expenditures. In addition, that refined model could account for new venture bankruptcy, thus making survival maximization a natural research extension.

We could also further contribute to the marketing literature by segmenting the market, expenditures, and new ventures to explicitly account for customer retention. Fruchter and Zhang (2004) offer an in-depth treatment of offensive and defensive marketing strategies in a mature market. Sophisticated customer retention policies have been mostly associated with mature firms, however. We could model a new venture's effectiveness and expenditures in retaining its customers in addition to considering stochastic changes to market share and sales as in the work of Prasad and Sethi (2004) for a mature product category. In addition, our model could be augmented to include the effect of an increase in the rival's expenditures to attract unrealized customers on the number of unrealized customers a new venture attracts. Finally, we do not keep track of a customer's prior purchase history (e.g., as in Mueller, 1983). Since we consider a finite horizon for an industry in its nascent period, we argue that there is insufficient time for this lack of distinction to affect our results. Nevertheless, modeling customers who depart the industry as a separate customer segment may change expenditure patterns. Far from closing the debate on this area of research, our study and models lend themselves to several research extensions and we hope that others will follow us in this quest.

Chapter 2

Integrating Customer Preferences with Technology Adoption and Product Redesign in a Duopoly

2.1 Introduction

Over the past few decades, research has shown that the time lag between new versions of high-tech products (Mahajan et al., 1993) and the time required for a new product to diffuse into the mainstream (Hauser et al., 2006) have been steadily decreasing. Latest advances in technology are increasingly being implemented in both high- and low-tech products and services to deliver a better customer experience. General Motors and Nintendo provide examples of newly implemented technology in the area of communications, having added the OnStar® communication system and Bluetooth®, respectively. On the service side, Netflix and eHarmony have added pattern-matching technology (to match customers with DVDs and mates, respectively). In the personal computing industry, Hua and Wemmerlöv (2006) found that a firm's ability to rapidly release new versions of an original product leads to increased sales and market share. However, contrary to their hypothesis, they were unable to conclude that greater technological competence — or a more radical product change — increases sales. Thus, even in high-tech industries, adding technology for the purpose of increasing sales may be suboptimal. In this paper we study when firms should add technology to an existing product in order to guarantee increased profits.

We focus on tangible technology embedded in the firm's primary product, which affects a customer's day-to-day interaction with the product. The technology can be closely integrated into the original product, as with touch-screen technology which, for instance, substantially affects how customers interact with their phones. Alternatively, the technology can be loosely integrated with the original product as an added component, such as voice-dial technology for phones (customers can still use a keypad to make calls). Within the framework of our focus, customers do not view the technology choice as "more is better." Rather, technology preferences represent the heterogeneous tastes of different customer segments regarding whether adding technology to the product would convince them to purchase (or not).

Studying technology adoption decisions is important because firms that add technology often fail to meet sales expectations. We draw examples from the so-called "smartphone" market to illustrate how technology adoption can hurt a firm.[6] As smartphone manufacturers attempt to add PDA capabilities, they might fail to meet sales expectations because the redesign might be adding a technology that customers do not want. Some customers may not want touch screens on their phones because touch screens do not offer the speed and tactile feedback of a keypad (V, 2008). On the other hand, adding technology may increase sales by luring more customers from a rival. In addition, if the product is in the early phases of its lifecycle, the firm can increase sales by attracting large numbers of prospective customers (i.e., those who are currently not purchasing). Kim and Mauborgne (2005) recently found that only 14% of product launches were aimed at attracting prospective customers (as opposed to competing for existing customers), yet that 14% accounted for 61% of total profits.

A second area of risk involved with adding technology lies in the product-technology fit (i.e., the product redesign to accommodate the new technology). Customers who liked the concept of a technology-enhanced product may balk at purchasing the redesigned product because some characteristics of the original product were changed or eliminated. For instance, Apple decided not to offer a keypad to use with the touch screen of the iPhone, and yet reviewers report that a keypad is much faster for typing than a touch screen (V, 2008). In addition, some customers returned their iPhones and purchased Blackberry smartphones because the iPhone phone functions were not as good as those of the Blackberry (Moore, 2000). To increase total sales, Apple must balance the needs of existing customers who previously used keypads and the needs of prospective customers who may have never used keypads. Thus, firms should redesign their products to match as closely as possible the ideal product-technology fit of their customer segments. But even when customers favor adding technology and are pleased with the product-technology fit, the firm still may not increase its market share relative to its rival. A firm's rival with a superior reputation for technology and product design will most likely attract more customers by adding technology. Apple's reputation for innovation and design arguably increased customer interest in the iPhone, even though it was not the first smartphone to feature touch-screen technology.

To better model different customer perspectives, we divide the customer pool into the prospective customer segment and each firm's existing customer segment. Our market segmentation is most appropriate for markets in which the product is in the introductory or growth phases of its lifecycle. At that stage, existing customers tend to be innovators or early adopters (Moore, 2000) and have accumulated product experience as they have interacted with a firm's product (Alba and Hutchinson, 1987). But prospective customers at this point often require additional information (Moore, 2000) and product-related benefits (Dorf and Byers, 2005). Therefore, each group is likely to have different opinions on adding technology and on what the subsequent product redesign should be. We therefore ask: *Given the preferences of prospective and existing customers for technology-enhanced products, and given the ideal product-technology fit of each customer segment, when does adding technology increase profit for a firm engaged in duopoly competition?*

We propose a two-stage framework to answer this question. In Stage 1, firms are simultaneously given the opportunity to add exogenous technology to their product. Firms know how each customer segment will react to their choices. After both firms announce their decisions, if either firm added technology, it undergoes Stage 2 in which product redesign occurs as the firm merges the added technology with the original product. As the firm increases redesign spending, it can attain a better fit between the original product and the new technology. The firms also know how each customer segment will respond to different product-technology fit levels. The game concludes with the product being launched and customers making their purchase decisions. Section 2.2 reviews the pertinent literature on technology selection and sales attraction, and §2.3 describes the decision model underlying this game. Section 2.4 highlights the optimal product redesign decision, while §2.5 introduces the equilibrium concept for the technology adoption decision and discusses special cases. Section 2.6 concludes this study and summarizes our findings. Proofs of our propositions appear in the appendix.

Our contributions to the technology and engineering management literature are threefold. First, we focus on products for which technology innovation and redesign decisions should be driven primarily by customer preferences. Our approach of splitting the firm's decision into an adoption decision and product redesign decision helps measure how customer opinion may change once the technology-enhanced product is available and not merely conceptual. Second, we concentrate on conditions under which both firms are advised to add technology. Our discussion of the barriers to *standardization* (i.e., when both firms select the same technology decision) complements the literature on technology adoption games. Third, we provide insight as to when a firm is most likely to select a drastic product redesign, thus balancing the literature on dominant design and radical innovation.

2.2 Background Literature

We first examine the literature on factors that firms must consider when selecting a technology. This review demonstrates how we fill a gap in the research on customers' perspective on technology. We then discuss the literature on customer preferences for technology and product redesign. This section is concluded with an explanation of how our model connects these elements, to allow us to contribute to existing literature.

Selecting the right technology can create both sales and profit advantages (Hauser et al., 2006). Previous research has shown that technology that solves a market need can lead to a significant competitive advantage via radical innovation (Chandy and Tellis, 2000), enable late entrants to better compete with first movers (Bohlmann et al., 2002), make new products more "fashionable" (Peters, 1992), and improve the product's usability for customers or suppliers (Sanchez and Collins, 2001). Firms add technology in pursuit of various financial and non-financial benefits. For instance, increasing the quality of the customer’s experience can be a greater driver than cost reduction in motivating a firm to add advanced manufacturing technology (Lefebvre et al., 1996). For our work, firms add technology to increase total firm sales (and thus profit).

Previous research on whether a firm should adopt technology (or release a new version of its product) studies the effects of that adoption on the quality of production output and/or on marginal cost (e.g., Giminez 2006, Owen 2006) as well as how the frequency of product introductions should depend on firm capabilities and the cost of product introduction (e.g., Meyer and Utterback 1995, Iansiti 1995, Souza 2004, Souza et al. 2004). Empirical analyses (e.g., Meyer and Utterback 1995, Iansiti 1995) tend to focus on internal issues such as the firm’s research and development capabilities rather than customer technology preferences. As a result, models that consider the tradeoffs in sales volume due to adding technology, and that include customer segmentation, are under-investigated. For example, Amaldoss and Rappoport (2005) only investigate competition for existing customers, while Axelrod et al. (1995) mention in passing that technology affects market share, but do not explicitly model its effects on customers. Dhebar (1994) does allow for existing customers to delay purchase if a product with significantly higher quality will soon be released, but the model is only for one firm and assumes that increased research and development will always lead to increased product quality.

The effect of technology on customers (and thus the influence of customers on technology selection) is critical. A recent study revealed that 49% of Americans barely use modern communication and information technology, and another 10% use it fairly regularly but are frustrated with their experience (Horrigan, 2007). These statistics provide additional support for our customer group segmentation. If the product is already high-tech, then existing customers may welcome the added technology. They most likely are part of the 41% of Americans who consider technology to be a net benefit. However, prospective customers may become more difficult to attract. Because of this, we make a distinction between prospective and existing customers (depending on which firm an existing customer belongs to), and analyze the effects of technology on each segment during both pre-technology adoption (Stage 1) and post-technology adoption (Stage 2). Farrell and Saloner (1986) consider technology adoption decisions at the customer level for both new and existing users, but assume that the new technology is superior to the status quo. We bring insight to this literature by modeling the technology adoption decision for the firm according to the impact of technology on customer preferences (and hence sales).

Existing models (e.g., Katz and Shapiro 1985, Farrell and Saloner 1985, Kauffman and Li 2005) compare technologies according to network-generated benefits (i.e., the customer's valuation of the product increases as the number of users increase) and network-independent benefits. Because standardization expands the network size, it is assumed to yield positive externalities for customers and increase sales for the firms that add technology. However, possessing the right technology may be more profitable than positive externalities from standardization. Examples include the work of Belleflamme (1998), in which the technology itself is more important than the rival's selection, or Axelrod et al. (1995), in which the firm gains competitive advantage if its rival does not add technology. In addition, as argued by scholars (Besen and Farrell 1994, Hauser et al. 2006) for some product categories, factors such as customer preference for differentiated products may impose negative externalities from standardization.

Because of this, we emphasize customer preferences for technology as the key determinant of whether standardization of added technology can increase total sales. Aldrich and Fiol (1994) argue that, in a nascent industry, outsiders' perceived reliability or legitimacy of the product is lowered when the product technology is not standardized.[7] However, differentiation may lead to increased sales for both firms when standardization results in net sale losses from competition (Katz and Shapiro 1985). Our work benefits the literature on standardization (e.g., Farrell and Saloner 1988, Van Wegberg 2004) by describing how customer preferences for standardization create barriers to both firms adding technology, and reporting whether the firm would increase profit by overcoming such barriers. The firm may increase sales by not standardizing; for example, the case study of Rice and Galvin (2006) notes that Nokia and Ericsson intentionally selected different technologies early in the product lifecycle.

On the product redesign side, previous studies have shown that to increase the chances of successful technology adoption, firms must redesign the product being sold in order to integrate the technology with the product. For instance, Liberator and Breem (1997) found that firms that reengineered their work processes to better accommodate the adoption of digital-imaging technology were most successful in implementation. In addition, Rogers (2003) observes that the speed of technology acceptance depends on compatibility (changes that the new technology requires in present operations) and complexity (understandability of the new technology). We build on this research by including a second stage, that of post-adoption (the product redesign phase), in which firms engineer the synthesis of technology and product in order to meet customer needs and thus maximize profits. Our contribution is to treat integration as a decision variable, positioning it as the product-technology fit.

Further, firms wish to set product-technology fit to minimize the adjustments a customer must make in order to use their product. For instance, in their marketing and testing efforts, manufacturers of information technology products emphasize both the usefulness and perceived ease of use of final products via a technology acceptance model (Davis 1989, Davis and Venkatesh 2004). For our product redesign stage, we draw upon the terminology of Henderson and Clark (1990) to describe the firm's choice for product-technology fit. The firm can opt for *component innovation* (the addition of technology as a new component without changing the overall product architecture), *radical innovation* (a complete redesign of the product architecture to achieve full technology-product integration), or a point between the two extremes. We can thus contribute to existing literature by identifying new factors that cause a firm to initiate radical innovation.

Increasing product-technology fit typically improves the usefulness of the product; therefore it would seem that firms should always opt for radical innovation if they can afford it. However, radical innovation may make the product more difficult to use, especially for existing users who must retrain themselves. March (1994) notes that managers must also consider product usability when considering product design decisions. In addition, prospective customers may be so focused on the potential usefulness of the product that they fail to consider ease-of-use problems that may increase when technology is added. Thompson et al. (2005) report that, when asked to select between digital video players with a high, medium, or low number of features (adding technology typically increases the number of features), 63% chose the player with the highest number of features. However, after using it, less than 50% still rated the high-featured player as best. Being required to learn more in order to use the extra features frustrated many of those customers. We can thus deal with a new aspect of the product redesign literature by prescribing when firms should opt for component rather than radical innovation based on the preferences of prospective and existing customers.

Previous product design models that focus on customer response assume that manufacturing and/or design cost increases quadratically in quality (e.g., Desai 2001, Desai et al. 2001, Krishnan and Gupta 2001). In the context of our model, this indicates that radical innovation increases product design cost because it not only changes the component but also the relationships between components. Hence, we include such a quadratic redesign cost that increases as the product-technology fit is improved. This allows us to identify when firms should not opt for radical innovation because the redesign cost outweighs its benefit — another contribution to the existing literature. We also contribute to previous product design models (such as Desai 2001, Desai et al. 2001, Krishnan and Gupta 2001) by stressing the engineering management aspects of the decision. Our customer segmentation divides customers by past product experience rather than assuming the existence of a high-quality and low-quality segment. We do not model product-technology fit or technology as “more is better” variables, but instead allow for greater complexity in customer preferences (and thus the firm’s response to those preferences).

2.3 Model Formulation

2.3.1 Decision Context and Operationalization

Prior to formulating our model, we explain its structure in six steps and make explicit the assumptions that underlie each step. The sequence of events opens with both firms selling their original products without adding technology (i.e., maintaining the status quo). The firms sell a similar product at the status quo and hence the experience and product attitudes of each firm's existing customers are comparable. We now describe the six steps.

Step 1: Stage 1, the technology adoption stage, begins and both firms consider whether to add technology based on both the distinct customer segments' preferences for the technology-enhanced product and the reaction of the firm's rival.

Step 2: Stage 1 ends when both firms simultaneously announce their technology adoption decisions.

Step 3: Stage 2, the product redesign stage, begins and the firm(s) (if any) that committed to technology adoption must now redesign their product to accommodate the added technology.

Step 4: Those firm(s) that committed to technology adoption determine the product-technology fit in order to match the fit desired by each customer segment.

Step 5: Stage 2 ends with both firms simultaneously launching their products.

Step 6: The game concludes with customers making their purchase decisions and firms calculating the resulting profits from sales minus the product redesign cost.

For Step 1, we assume complete knowledge for both firms on technology preferences of each customer group for all *technology outcomes*. The four possible technology outcomes are the two standardization possibilities (both firms maintain status quo or both firms add technology) and the two diversification possibilities (only one of the firms adds technology). We also assume that the changes in the firm's effectiveness at selling the product to each customer segment can be taken as a proxy for the customers' technology preferences.

In practice, the level of effectiveness for *attracting* prospective customers, *acquiring* the customers of the firm's rival, and *retaining* the firm's current customers can be obtained via survey instruments. Effectiveness can be measured by asking prospective customers to rank the four technology outcomes according to their willingness to purchase, and taking the results in aggregate to form a ranking. More powerful market research techniques could also be applied such as voice-of-the-customer (to discover if a given customer segment prefers adding technology) and conjoint analysis (to measure the value a given customer segment ascribes to services with — as opposed to services without — the added technology).[8] However, some products and/or technologies may be unfamiliar to customers, causing survey information to possess only limited value. In cases such as this, some scholars recommend that broader questions on customer attitudes toward innovation and technology should be asked, and customer responses can be mapped onto measurement scales to predict which customers will adopt the new product (Roehrich, 2004).

For Step 2, both firms make their decisions simultaneously (as in, e.g., Belleflamme 1998). We assume that the technology is being supplied by an exogenous source, and thus it makes sense that both firms are approached by or notice the technology around the same time. As to the announcement itself, our assumption works well for the many firms that schedule product announcements to coincide with industry trade shows or quarterly earning reports.

For Step 3, we make the implicit assumption that the technology decision is the main determinant of whether the firm will update its product or not. If a firm decides not to add technology, it will continue selling its original product and thus has no product redesign decision in Stage 2.

For Step 4, the *ideal product-technology fit levels* for customers (i.e., their preferred level of product-technology fit in the redesigned product) can be measured directly by asking customers about their expectations for the technology-enhanced product, or more indirectly by observing customers interacting with prototypes of the technology-enhanced product (Stein and Iansiti, 2007). For instance, smartphone firms first might ask if customers desire a touch screen if it did not change existing features (no product-technology integration); then ask if customers would prefer to use a touch screen to navigate the Web rather than keypad arrows (partial integration); and finally ask if customers would still purchase if a touch screen phone had no tangible keypad (full integration). The firm can subsequently map this information onto a 0-1 product-technology fit scale. The 0 indicates that the customer does not want any redesign for the sake of adding technology (component innovation), and the 1 indicates that the customer insists on a complete product redesign with no thought of retaining existing features for the sake of customer familiarity (radical innovation).

Also for Step 4, we assume customer segments can prefer (or, alternatively, fix their expectations on) one ideal product-technology fit between the original product and the added technology. Because customers have access to publicly available pre-launch information (e.g., firm marketing materials or product previews), can perform comparisons with similar products, or possess previous experience with the firm's original product, each customer segment possesses an ideal image of the redesigned product. We thus assume that there is one ideal fit that is best for a customer depending on which firm's product, if any, a customer has used. Since prospective customers, by definition, have no expertise with the original product, they have no inherent bias toward retaining features of the original product. Thus, we assume that prospective customers always prefer a *higher* level of product-technology fit than either firm's existing customer segment.

For Step 5, assuming a simultaneous launch date (e.g., to coincide with the winter holiday season) means that the firms have no opportunity to learn from how customers responded to a rival's product-technology fit. Each firm must make its best conjecture about the product-technology fit based solely on ideal product-technology fits for each customer segment. In subsequent product releases, the firms may indeed begin copying each other or differentiating from each other's product to gain market share, but that is outside the scope of this model.

Finally, for Step 6, we assume that the timeframe in which customers purchase is short enough for the firm's technology adoption and product redesign decisions to be the main determinant of whether customers will purchase from that firm. Based on Thompson et al. (2005), where the difficult-to-use product lost at least 10% of the market once would-be customers interacted with the product, we also assume that firms that do not match a customer segment's ideal product-technology fit in Step 4 lose sales in Step 6.

2.3.2 Decision Variables and Firm Sales

In Stage 1, each of two firms (firm *i*, firm *j*) decides whether to add technology or to maintain its status quo. The technology adoption decision is modeled by binary decision variables $\varphi_i = \{0,1\}$ and $\varphi_j = \{0,1\}$, for firm *i* and *j*, respectively, where 0 corresponds to maintaining the status quo and 1 to adding technology. In Stage 2, if a firm chooses to add technology which results in undertaking product redesign, that firm must also select a product-technology fit level $\Theta_i \in [0,1]$ or $\Theta_j \in [0,1]$, for firm *i* and *j*, respectively. Radical innovation is associated with values of Θ_i near 1, while component innovation is associated with values of Θ_i near 0. Higher levels of Θ_i are assumed to result in higher redesign costs because the firm must make more product changes during Stage 2.

Most of our attention here focuses on firm *i* because sales and profit for firm *j* can be derived straightforwardly by symmetry. Firm *i*'s current number of sales units are denoted $S_{i,0}$ and are totaled before the Stage 1 technology decision. We partition current industry customers by firm as $S_{i,0}$ and $S_{j,0}$, the existing sales of each firm.[9] Prospective sales that do not belong to either firm are denoted as N_0. These sales can be estimated by assuming a market (industry) ceiling and subtracting current industry sales from that ceiling (as in, e.g., Erickson 2003, Fruchter 1999). Firm *i* is able to attract a percentage of customers from each segment. We denote those components of the sales function as A_i for attracted prospective customers, B_i for acquired existing customers of firm *j*, and C_i for retained existing customers of firm *i*. Final sales (i.e., those after the Stage 2 decision is made and the product is launched) for firm *i* are thus of the form $S_i = A_i N_0 + B_i S_{j,0} + C_i S_{i,0}$.

Each component of the final sales function has two subcomponents: (1) an *effectiveness function* measuring the customer segment's interest in purchasing the product given a technology outcome, and (2) a *fit function* measuring how many of those customers will purchase given the product-technology fit decision associated with that technology outcome. We next build mathematical expressions to describe each subcomponent and the firm's profit optimization function.

2.3.3 Components of the Final Sales Equation

The structure of each component is similar to the demand model for new product versions in Bhattacharya et al. (1998), in which sales are equal to the multiplication of a difference term (price minus product attractiveness as a function of technology choice) and market size. To match our focus on the customer perspective, our difference term is a fit function, that measures how closely the redesigned product matches pre-launch customer expectations, subtracted from the effectiveness function, which measures how attractive a product is to customers pre-product launch.

We begin by describing the effectiveness function for component A_i. Firm *i*'s *attraction effectiveness* (effectiveness in attracting prospective customers) is denoted as $\beta_i(\varphi_i,\varphi_j)\in(0,1)$ and, similarly for firm *j*, $\beta_j(\varphi_i,\varphi_j)\in(0,1)$. Specifically for firm *i*, it will attract a fraction $\beta_i(0,0)$ of prospective customers if both firms retain the status quo, $\beta_i(1,0)$ if it is the only firm to add technology, $\beta_i(0,1)$ if it is the only firm *not* to add technology, and $\beta_i(1,1)$ if both firms add technology. Using the binary technology adoption variables, we can express the effectiveness function mathematically as

$$\beta_i(\varphi_i,\varphi_j)=[1-\varphi_i][1-\varphi_j]\beta_i(0,0)+\varphi_i[1-\varphi_j]\beta_i(1,0)+[1-\varphi_i]\varphi_j\beta_i(0,1)+\varphi_i\varphi_j\beta_i(1,1)\,. \quad (2.1)$$

The second subcomponent of A_i is the fit function. We model fit separately from effectiveness because while some customers plan to purchase when the initial announcement of technology addition is made, they may balk at purchasing the redesigned product. We denote the fit function for attraction by $f_i(\varphi_i,\varphi_j,\Theta_i,\Theta_j)$. This function measures the number of lost sales due to a misfit between the firm's product-technology fit and the prospective customer's ideal product-technology fit. We represent that ideal fit by $\theta_n\in(0,1)$ (which will be further explained below). We build on d'Aspremont et al. (1979), who applied quadratic transportation costs to Hotelling's linear city (1929) where the firm loses sales at a rate of $\left[\Theta_i-\theta_n\right]^2$. Using this quadratic loss function means that few customers are lost when the form's product-technology fit and the customers' ideal product-technology fit are similar, but the number of non-purchasers grows at an increasing rate as the difference in fit widens.

However, we do deviate from Hotelling in that we do not assume that customers are uniformly distributed in their preferences for product-technology fit. Instead, we assume that all prospective customers expect the product to be located at a certain point (i.e., their ideal product-technology fit level θ_n), and they would all purchase it if the firm's product technology fit were to match their ideal product-technology fit (i.e., $\Theta_i^* = \theta_n$). If, however, the product is located at $\Theta_i \neq \theta_n$, a misfit occurs and the firm loses prospective customers at the quadratic rate shown above. Note that θ_n does not necessarily equal 1 because prospective customers may not be in favor of radical innovation if it forces them to interact with a difficult-to-use technology.

By itself, the quadratic loss function is an incomplete explanation of how many prospective customers would be lost due to misfit. In some industries, customers would still purchase out of necessity even if the redesigned product did not reach their ideal level, while in others, would-be customers would be much more likely to balk at purchasing. We thus adjust the quadratic loss function by a scaling factor to measure the likelihood of would-be customers balking if a misfit occurs. A high level of $a_{ii} \in (0, \min(\beta_i(1,0), \beta_i(1,1))$, which measures the impact of firm *i*'s product-technology misfit on firm *i*'s attraction, indicates that more of firm *i*'s prospective customers balk at purchasing. Similarly, we use a scaling factor, $a_{ji} \in (0, \min(1-\beta_i(0,1), 1-\beta_i(1,1), a_{jj}))$ to determine the impact of prospective customers' misfit with firm *j*'s product-technology fit on firm *i*'s attraction. Note that a_{jj}, $a_{jj} \in (0, \min(\beta_j(0,1), \beta_j(1,1))$, will always be greater than a_{ji} because not all of the prospective customers who balked at purchasing from firm *j* due to misfit will instead purchase from firm *i*.

Therefore, when no firm adds technology, the fit function is $f_i(0,0,\Theta_i,\Theta_j)=0$, whereas if only firm *i* adds technology, it is $f_i(1,0,\Theta_i,\Theta_j)=-a_{ii}[\Theta_i-\theta_n]^2$. In other words, a $a_{ii}[\Theta_i-\theta_n]^2$ fraction of previously interested prospective customers now refuse to buy due to product-technology misfit. Firm *j* benefits from this with $a_{ij}[\Theta_i-\theta_n]^2$ additional sales, where $a_{ij}\in(0,\min(1-\beta_j(1,0),1-\beta_j(1,1),a_{ii})$. Similarly, if only firm *j* adds technology, firm *i* benefits via firm *j*'s prospective customers and $f_i(0,1,\Theta_i,\Theta_j)=a_{ji}[\Theta_j-\theta_n]^2$. Finally, if both firms add technology, the effects are combined and firm *i* loses some of its prospective customers while gaining some of firm *j*'s; formally, $f_i(1,1,\Theta_i,\Theta_j)=a_{ji}[\Theta_j-\theta_n]^2-a_{ii}[\Theta_i-\theta_n]^2$. The fit function can thus be expressed as

$$f_i(1,1,\Theta_i,\Theta_j)=\varphi_j a_{ji}[\Theta_j-\theta_n]^2-\varphi_i a_{ii}[\Theta_i-\theta_n]^2, \tag{2.2}$$

and combining the effectiveness and fit functions, the first component of the sales function is

$$A_i=\beta_i(\varphi_i,\varphi_j)+f_i(\varphi_i,\varphi_j,\Theta_i,\Theta_j)\,. \tag{2.3}$$

Note that $A_i\in(0,1)$ because of the constraints on a_{ii} and a_{ji}. Not all prospective customers will be attracted to a firm (i.e., $\beta_i(\varphi_i,\varphi_j)+\beta_j(\varphi_i,\varphi_j)<1$), and thus $A_i+A_j<1$.

Component B_i models *acquisition*, which is firm *i*'s ability to add existing customers from firm *j*. (Equivalently, for firm *j*, component B_i models firm *j*'s ability to add existing customers from firm *i*.) For the effectiveness subcomponent, firm *i*'s *acquisition effectiveness* (effectiveness in acquiring the customers of firm *j*) is denoted as

$\rho_i(\varphi_i, \varphi_j) \in (0,1)$ and, similarly for firm *j*, $\rho_j(\varphi_i, \varphi_j) \in (0,1)$. Using the same reasoning as for $\beta_i(\varphi_i, \varphi_j)$ leads to

$$\rho_i(\varphi_i, \varphi_j) = [1-\varphi_i][1-\varphi_j]\rho_i(0,0) + \varphi_i[1-\varphi_j]\rho_i(1,0) + [1-\varphi_i]\varphi_j\rho_i(0,1) + \varphi_i\varphi_j\rho_i(1,1). \quad (2.4)$$

We now introduce the fit function for acquisition, $g_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j) \in (0,1)$. A redesigned product with high product-technology fit loses some of its original characteristics and may also be more difficult to use than the original product. We thus assume that a fraction of existing customers depart to the firm's rival if the product redesign results in radical innovation that renders their prior experience with the product obsolete. On the other hand, if the product-technology fit is low, less-experienced existing customers will object because they prefer a better product-technology fit over retaining characteristics of the original product.

We again assume that existing customers have an ideal level for the product-technology fit and denote this as $\theta_i \in (0,1)$. In similar fashion to component A_i, we modify the relationship between product-technology fit and acquisition by a scaling factor $b_{ii} \in (0, \min(\rho_i(1,0), \rho_i(1,1))$ for the impact of firm *i*'s product-technology misfit on firm *i*'s acquisition. For the impact of firm *j*'s product-technology misfit on firm *i*'s acquisition, $b_{ji} \in (0, \min(1-\rho_i(0,1), 1-\rho_i(1,1), c_{jj})$. Besides its own effectiveness, firm *i* is limited in how many customers of firm *j* it can acquire due to the scaling factor $c_{jj} \in (0, \min(1-\rho_i(0,1), 1-\rho_i(1,1))$, which measures the impact of firm *j*'s product-technology misfit on firm *j*'s retention. The scaling factor is c_{jj} rather than b_{jj} because firm *j*'s final sales component for its sales is the retention component C_j.

When no firm adds technology, $g_i(0,0,\Theta_i,\Theta_j)$ = 0. When firm *i* adds technology, increasing the difference between product-technology fit Θ_i and customer ideal product-technology fit θ_j of firm *j*'s existing customers decreases firm *i*'s ability to acquire firm *j*'s customers. The fit function when firm *i* is the only firm to add technology becomes $g_i(1,0,\Theta_i,\Theta_j) = -b_{ii}[\Theta_i - \theta_j]^2$. In contrast, if only firm *j* adds technology, then firm *i* may acquire some (but not necessarily all) customers of firm *j* who experience a misfit, and thus $g_i(0,1,\Theta_i,\Theta_j) = b_{ji}[\Theta_j - \theta_j]^2$. If both firms add technology, the fit function sums up to $g_i(1,1,\Theta_i,\Theta_j) = b_{ji}[\Theta_j - \theta_j]^2 - b_{ii}[\Theta_i - \theta_j]^2$. Firm *i* will increase its acquisition if, given the customers' ideal product-technology fit for firm *j*, its optimal fit is a better match than firm *j*'s optimal fit. The fit function for acquisition is thus

$$g_i(\varphi_i,\varphi_j,\Theta_i,\Theta_j) = \varphi_j b_{ji}[\Theta_j - \theta_j]^2 - \varphi_i b_{ii}[\Theta_i - \theta_j]^2 . \qquad (2.5)$$

Note that $B_i \in (0,1)$ because of the constraints on b_{ii} and b_{ji}. Firm *i*'s gain in $S_{j,0}$ sales is firm *j*'s loss, and thus $B_i + C_j < 1$. This concludes the description of component B_i, which measures the fraction $S_{j,0}$ of firm *j* sales acquired by firm *i* as

$$B_i = \left[\rho_i(\varphi_i,\varphi_j) + g_i(\varphi_i,\varphi_j,\Theta_i,\Theta_j)\right]. \qquad (2.6)$$

Similarly, component C_i measures the acquisition of firm *j* or, equivalently, the *retention* of firm *i*, where retention is firm *i*'s ability to maintain its existing sales levels despite firm *j*'s acquisition. The effectiveness and fit functions for C_i are much like that of B_i except for the difference in scaling factors due to modeling both existing customer segments. In similar fashion to component B_i, we modify the relationship between product-technology fit and acquisition by a scaling factor,

$c_{ii} \in (0, \min(1-\rho_j(1,0), 1-\rho_j(1,1))$, for the impact of firm *i*'s product-technology misfit on firm *i*'s retention, and $c_{ji} \in (0, \min(\rho_j(0,1), \rho_j(1,1))$ for the impact of firm *j*'s product-technology misfit on firm *i*'s retention. The fit function for retention is therefore

$$h_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j) = \varphi_j c_{ji}[\Theta_j - \theta_i]^2 - \varphi_i c_{ii}[\Theta_i - \theta_i]^2, \tag{2.7}$$

and the component is thus

$$C_i = \left[1 - \rho_j(\varphi_i, \varphi_j) + h_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)\right]. \tag{2.8}$$

Note that $C_i \in (0,1)$ because of the constraints on c_{ii} and c_{ji}. Firm *i*'s lost initial sales will either be acquired by firm *j* or depart the industry altogether, and thus $B_i + C_j < 1$.

2.3.4 Objective Function

Combining Equations 2.3, 2.6, and 2.8 yields the final sales equation as

$$\begin{aligned} S_i = &\left[\beta_i(\varphi_i, \varphi_j) + f_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)\right]N_0 \\ &+ \left[\rho_i(\varphi_i, \varphi_j) + g_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)\right]S_{j,0} \\ &+ \left[1 - \rho_j(\varphi_i, \varphi_j) + h_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)\right]S_{i,0}\,. \end{aligned} \tag{2.9}$$

We assume that the effect on profit margin per unit due to adding technology is negligible, which is reasonable for products in the early stages of their lifecycle. In other words, both firms can price products to maintain a unit profit margin (price minus cost) of π_i and π_j even if the firms adopt technology. We justify this assumption about pricing by noting that before a product attains a mature phase, its characteristics that win sales tend to be product features and performance, not price (Slack and Lewis, 2008). Similarly, from the technology adoption lifecycle, the more price-sensitive customers do not appear until the product has already been adopted by a significant fraction of the majority (Moore 2004).

We do include a redesign cost factor, which we denote as D_i. Merging the technology with the original product is a process that becomes more costly as the firm strives to fit the technology more closely to the original product architecture. We assume that the redesign cost grows at an increasing rate as product-technology fit increases, in a fashion equivalent to how quality increases the cost of product design and manufacture (Desai 2001, Desai et al. 2001, Krishnan and Gupta 2001). Thus, the firm must pay $D_i\Theta_i^2$ to redesign the product if it adds technology. Firm *i*'s objective is to maximize its profit $P_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)$. Formally,

$$\underset{\varphi_i \in \{0,1\},\, \Theta_i \in (0,1)}{\text{Max}} P_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j) = \underset{\varphi_i \in \{0,1\},\, \Theta_i \in (0,1)}{\text{Max}} \pi_i S_i - \varphi_i D_i \Theta_i^2 \quad \text{with} \quad S_i > 0\,. \tag{2.10}$$

Table 2.1 summarizes notation for firm *i*, which can be adjusted in an obvious manner to firm *j*.

Table 2.1 Notation summary for firm *i*

Type	Description	Notation	Description	Notation
Decision variables	Technology adoption decision	φ_i	Product-technology fit decision	Θ_i
Functions of decision variables	Effectiveness function for attraction	$\beta_i(\varphi_i, \varphi_j)$	Effectiveness function for acquisition	$\rho_i(\varphi_i, \varphi_j)$
	Fit function for attraction	$f_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)$	Fit function for acquisition	$g_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)$
	Fit function for retention	$g_i(\varphi_i, \varphi_j, \Theta_i, \Theta_j)$		
Parameters	Impact of product-technology fit on firm *i*'s attraction	a_{ii}	Unit profit margin	π_i
	Impact of product-technology fit on firm *j*'s attraction	a_{ij}	Initial sales	$S_{i,0}$
	Impact of product-technology fit on firm *i*'s acquisition	b_{ii}	Product redesign cost factor	D_i
	Impact of product-technology fit on firm *j*'s acquisition	b_{ij}	Ideal product-technology fit for its existing customers	θ_i
	Impact of product-technology fit on firm *i*'s retention	c_{ii}	Impact of product-technology fit on firm *j*'s retention	c_{ij}

2.4 Product Redesign Decisions

We proceed to solve the two-stage game by implementing the commonly used technique of backward induction (Dixit and Skeath, 1999). To simplify exposition, we refer to firm *i* as *the firm* and firm *j* as *the rival* when necessary. We first solve the game at Stage 2 for the optimal level Θ_i^* of product-technology fit and focus on interior solutions for the purposes of sensitivity analysis. Taking the first order derivative of P_i in Equation (2.10) with respect to Θ_i yields

$$\Theta_i^* = \frac{\left[a_{ii}\theta_n N_0 + b_{ii}\theta_j S_{j,0} + c_{ii}\theta_i S_{i,0}\right]}{\left[a_{ii}N_0 + b_{ii}S_{j,0} + c_{ii}S_{i,0}\right] + D_i / \pi_i}. \tag{2.11}$$

We note that the firm's Stage 2 decision is not affected by the rival's decision.

Prior to performing sensitivity analysis, we compare the firm's optimal product-technology fit level to that of the rival and to the ideal fit of each customer segment. Recall from §2.3.1 that the prospective customers' ideal product-technology fit is greater than that of either existing customer segment ($\theta_n > \theta_i, \theta_j$). We first note the impact of the ratio of redesign cost to unit profit margin on the optimal product-technology fit for both firms. Suppose that the firm has a low ratio, perhaps due to excellent product development capabilities that enable it to charge higher prices (e.g., Apple), while its rival has a high cost/profit margin ratio. If the impact of both firms' product-technology misfit is the same on each segment (e.g., $b_{ii} = c_{jj}$ for $S_{j,0}$), the firm's optimal product-technology fit will be greater than its rival's. This prescription results from the fact that the firm's product is relatively closer to radical innovation and is thus more appealing to prospective customers, while the rival's product is relatively closer to component innovation and is thus more appealing to the existing customer segment with the lowest ideal product-technology fit.

We further investigate where the optimal product-technology fit may be found on the continuum of possible product-technology fit values. There are four possibilities: $\Theta_i^* \geq \theta_n$, $\theta_n > \Theta_i^* \geq \text{Max}(\theta_i, \theta_j)$, $\text{Max}(\theta_i, \theta_j) > \Theta_i^* \geq \text{Min}(\theta_i, \theta_j)$, and $\Theta_i^* < \text{Min}(\theta_i, \theta_j)$. Intuitively, it would appear that a firm should never select the first possibility because, by increasing product-technology fit past the highest ideal product-technology fit, it suffers decreased numbers of customers from all three segments. We explore that conjecture and whether the other three possible ranges are feasible in Proposition 2.1. For Proposition 2.1, we have assumed without loss of generality that $\text{Max}(\theta_i, \theta_j) = \theta_i$.

Proposition 2.1: If the ideal product-technology fits of the various customer segments are ordered as $\theta_n > \theta_i > \theta_j$, then firm *i*'s optimal product-technology fit Θ_i^* satisfies

(a) $\theta_n > \Theta_i^*$ *and*

(b) if

$$[\theta_i - \theta_n]a_{ii}N_0 + [\theta_i - \theta_j]b_{ii}S_{j,0} + \theta_i D_i / \pi_i > 0\,, \tag{2.12}$$

$\theta_i > \Theta_i^*$, otherwise, $\theta_i \le \Theta_i^*$; *and*

(c) if

$$[\theta_j - \theta_n]a_{ii}N_0 + [\theta_j - \theta_i]c_{ii}S_{i,0} + \theta_j D_i / \pi_i > 0\,, \tag{2.13}$$

$\theta_j > \Theta_i^*$, otherwise, $\theta_j \le \Theta_i^*$.

The redesign cost increases as the firm increases the fit between product and technology and approaches radical innovation. Thus, Proposition 2.1(a) confirms our intuition that the firm has no incentive to ever increase the product-technology fit past the highest ideal point of all customer segments, and thus $\Theta_i^* < \theta_j$. Proposition 2.1(b) examines the second and third possible points for the optimal product-technology fit. It is of interest to know when the firm would either favor the ideal level of prospective customers ($\Theta_i^* \ge \theta_i$, and hence $\Theta_i^* \in [\theta_i, \theta_n)$), or set its optimal product-technology fit closer to that of existing customers with the lowest ideal level (i.e., $\Theta_i^* \in (\theta_j, \theta_i)$). For Proposition 2.1(b), the first two terms of Equation (2.12) compare the lost prospective sales from product-technology misfit for prospective customers to firm *j*'s existing customers, respectively. However, if the firm moves toward prospective customers, its redesign cost will increase. The third term ($\theta_i D_i / \pi_i$) indicates how many extra prospective sales the firm must add to compensate for redesign costs so that $\Theta_i^* \geq \theta_i$ is optimal. Thus, product redesign cost causes the firm to shift its optimal product-technology fit toward the existing customers with the lowest ideal product-technology fit, even if the potential sales from prospective customers may be higher.

In practice, the result of Proposition 2.1(b) indicates that a firm with a high redesign cost to unit profit margin ratio faces a high barrier to growth from attracting prospective customers. Such a firm is especially likely to focus on existing customers (i.e., $\Theta_i^* \in (\theta_j, \theta_i)$) if prospective customers are highly sensitive to product-technology fit (a_{ii} is relatively high). In fact, if redesign costs are high enough relative to unit profit margin, Proposition 2.1(c) shows that the firm's optimal product-technology fit may even be lower than its rival's ideal product-technology fit ($\theta_j - \Theta_i^* > 0$). Consequently, all customer segments would prefer a higher product-technology fit than the optimal product-technology fit offered by the firm, but the firm cannot afford to offer such a product.

We now perform sensitivity analysis by taking derivatives of the optimal solution in Equation (2.11) with respect to key model parameters. Table 2.2 offers a summary of our findings (note that straightforward derivations are omitted).

Table 2.2 Sensitivity of product-technology fit

Increases in	Product-technology fit Θ_i^*
D_i	$\downarrow$
π_i	$\uparrow$
θ_i	$\uparrow$
θ_j	$\uparrow$
θ_n	$\uparrow$
a_{ii}	$\uparrow$ if $[\theta_n - \theta_i]c_{ii}S_{i,0} + [\theta_n - \theta_j]b_{ii}S_{j,0} + \theta_n D_i / \pi_i > 0$
N_0	$\uparrow$if $[\theta_n - \theta_i]c_{ii}S_{i,0} + [\theta_n - \theta_j]b_{ii}S_{j,0} + \theta_n D_i / \pi_i > 0$
b_{ii}	$\uparrow$ if $[\theta_j - \theta_n]a_{ii}N_0 + [\theta_j - \theta_i]c_{ii}S_{i,0} + \theta_j D_i / \pi_i > 0$
$S_{j,0}$	$\uparrow$ if$[\theta_j - \theta_n]a_{ii}N_0 + [\theta_j - \theta_i]c_{ii}S_{i,0} + \theta_j D_i / \pi_i > 0$
c_{ii}	$\uparrow$ if $[\theta_i - \theta_n]a_{ii}N_0 + [\theta_i - \theta_j]b_{ii}S_{j,0} + \theta_i D_i / \pi_i > 0$
$S_{i,0}$	$\uparrow$ if $[\theta_i - \theta_n]a_{ii}N_0 + [\theta_i - \theta_j]b_{ii}S_{j,0} + \theta_i D_i / \pi_i > 0$

Key: $\uparrow$ for increase, $\downarrow$ for decrease

We first analyze the monotonic relationships. If the redesign cost component D_i increases, the firm should decrease its optimal product-technology fit. Conversely, an increase in profit margin per unit π_i should instead increase that fit, since the firm is better equipped to pay for it. In addition, if any customer segment experiences an increase in its ideal product-technology fit (i.e., $\theta_n, \theta_i, \theta_j$), the firm should also increase its fit. The relationships in Table 2.2 between Θ_i^* and the impact of firm *i*'s product-technology fit on firm *i*'s attraction (a_{ii}), and of prospective customers (N_0), are actually monotonic. The condition under which a decrease in a_{ii} or N_0 will increase Θ_i^* can be re-written as $\Theta_i^* > \theta_n$, and, from Proposition 2.1(a), this inequality never holds. Hence, if prospective customers become more sensitive to product-technology fit, then the firm should increase its fit to avoid losing more of these customers.

We compare these prescriptions for prospective customers with the work of Henderson and Clark (1990). They state that radical innovation is more frequent early in a product lifecycle. However, once a dominant design has arrived in an industry, new component knowledge (i.e., knowledge related to component innovation) becomes more valuable than new architectural knowledge (i.e., knowledge related to radical innovation). In a dominant-design situation, firm innovation is limited to smaller, component-level changes in the product design. For prospective customers, our result for product-technology fit agrees with Henderson and Clark. As more prospective customers become existing customers (thereby decreasing N_0) and the product moves through its lifecycle, radical innovation also decreases.

However, our result for a_{ii} and θ_n indicates that radical innovation could still occur after the dominant design is in place. Rogers (2003) indicates that prospective customers in the mainstream are more concerned than the prospective customers earlier in the lifecycle about how the technology-enhanced product relates to their existing systems (early majority type). Thus, as the product moves through its lifecycle, prospective customers become more insistent that the firm meet their ideal fit (a_{ii} increases). These customers may also increase their ideal product-technology fit (θ_n increases), and thus radical innovation may yet occur.

For the non-monotonic relationships, we articulate common patterns in Proposition 2.2.

Proposition 2.2: When $[\theta_i - \theta_n]a_{ii}N_0 + [\theta_i - \theta_j]b_{ii}S_{j,0} + \theta_i D_i / \pi_i > 0$, firm i should increase its optimal product-technology fit (Θ_i^*) if

(a) the impact of firm *i*'s product-technology fit on its acquisition (b_{ii}) increases;

or

(b) the firm's initial sales ($S_{i,0}$) increase;

but when $[\theta_j - \theta_n]a_{ii}N_0 + [\theta_j - \theta_i]c_{ii}S_{i,0} + \theta_j D_i / \pi_i > 0$, Θ_i^* increases if

(c) the impact of firm *i*'s product-technology fit on its retention (c_{ii}) increases;

or

(d) the rival's initial sales ($S_{j,0}$) increase.

For Propositions 2.2(a)-(b), the condition specified is the same as that of Equation (2.12), which, as we know from Proposition 2.1, can be rewritten as $\theta_i > \Theta_i^*$. Propositions 2.2(a)-(b) therefore indicate that when the firm's product-technology fit is lower than its existing customers' ideal product-technology fit (i.e., $\theta_i > \Theta_i^*$), and the sales the firm can retain increase, it should increase its product-technology fit toward θ_i. Similarly, Propositions 2.2(c)-(d) indicate that when $\theta_j > \Theta_i^*$, and the rival sales the firm can acquire increase, that firm should increase its product-technology fit. Thus, Propositions 2.2(b) and 2.2(d) together have an intuitive prescription for the firm. If the firm's optimal product-technology fit is located between the existing customer segments ($\text{Max}(\theta_i, \theta_j) > \Theta_i^* \geq \text{Min}(\theta_i, \theta_j)$), an increase in the number of existing customers with the lowest ideal fit ($\text{Min}(\theta_i, \theta_j)$) will decrease the optimal product-technology fit toward their ideal, and an increase in the number of existing customers with the highest ideal fit ($\text{Max}(\theta_i, \theta_j)$) will increase the optimal technology fit toward their ideal.

2.5 Technology Adoption Decisions

We characterize the Stage 1 solution based on the product-technology fit in Equation (2.11). The backward induction technique guarantees that the Stage 1 technology adoption decision is optimal for both stages, and if a firm adds technology, it implements its optimal Stage 2 decision on product redesign. Recall that four possible technology outcomes exist, representing the two possible technology decisions for each firm. Firm *i* maintains the status quo (i.e., $\varphi_i = 0$) or adds technology (i.e., $\varphi_i = 1$) to maximize its profit. That is, from Equations (2.1) – (2.11),

$$\underset{\varphi_i \in (0,1)}{\text{Max}}\ P_i(\varphi_i, \varphi_j) = \text{Max}\ \pi_i \begin{bmatrix} \left[\beta_i(\varphi_i,\varphi_j) + f_i(\varphi_i,\varphi_j,\Theta_i^*,\Theta_j^*)\right] N_0 \\ +\left[\rho_i(\varphi_i,\varphi_j) + g_i(\varphi_i,\varphi_j,\Theta_i^*,\Theta_j^*)\right] S_{j,0} \\ +\left[1-\rho_j(\varphi_i,\varphi_j) - h_i(\varphi_i,\varphi_j,\Theta_i^*,\Theta_j^*)\right] S_{i,0} \end{bmatrix} - \varphi_i D_i \Theta_i^{*2} > 0. \quad (2.14)$$

In our context, a *strategy* describes a firm's technology adoption decision given common knowledge, and may or may not depend on the rival's decision. We use Nash equilibria as our solution concept. A firm *regrets* its decision if, given its rival's choice, that firm would have increased profit by selecting the other action. If, for a given technology set, neither firm regrets its decision, then that set is a Nash equilibrium (or *regret-proof*). We confine our analysis to pure strategy Nash equilibria, assuming that the objective function in Equation (2.14) is common knowledge to both firms.[10] Table 2.3 contains the mathematical expressions for the sufficient conditions under which each outcome is a pure strategy Nash equilibrium. Any technology set can be a Nash equilibrium when at least one firm possesses a dominant strategy. For instance, {1,1} is a Nash equilibrium when $P_i(1,1) > P_i(0,1)$, $P_j(1,1) > P_j(1,0)$ and at least one of the firms makes more profit by being the only firm to add technology.[11]

Table 2.3 Nash equilibria

Firm i / Firm j	Firm j retains the status quo ($\varphi_j = 0$)	Firm j adds technology ($\varphi_j = 1$)
Firm i retains the status quo ($\varphi_i = 0$)	(1) $P_i(0,0) > P_i(1,0)$, *and* (2) $P_j(0,0) > P_j(0,1)$, *and* (3a) $P_i(0,1) > P_i(1,1)$, *or* (3b) $P_j(1,0) > P_j(1,1)$	(1) $P_i(0,1) > P_i(1,1)$, *and* (2) $P_j(0,1) > P_j(0,0)$, *and* (3a) $P_i(0,0) > P_i(1,0)$, *or* (3b) $P_j(1,1) > P_j(1,0)$
Firm i adds technology ($\varphi_i = 1$)	(1) $P_i(1,0) > P_i(0,0)$, *and* (2) $P_j(1,0) > P_j(1,1)$, *and* (3a) $P_i(1,1) > P_i(0,1)$, *or* (3b) $P_j(0,0) > P_j(0,1)$	(1) $P_i(1,1) > P_i(0,1)$, *and* (2) $P_j(1,1) > P_j(1,0)$, *and* (3a) $P_i(1,0) > P_i(0,0)$, *or* (3b) $P_j(0,1) > P_j(0,0)$

If there are zero Nash equilibria or {0,0} is a Nash equilibrium, then *standardization around the status quo* is the outcome of the game. Otherwise, the outcome may be *technology diversification with firm i maintaining its status quo* where the technology set {0,1} is a Nash equilibrium but {1,0} is not; *technology diversification with firm i adding technology* where the technology set {1,0} is a Nash equilibrium but {0,1} is not; or *standardization around adding technology* where the technology set {1,1} is a Nash equilibrium, but {0,0} is not. We proceed to analyze how the technology adoption decision affects profits in Equation (2.14) and subsequently specialize our analysis to the prospective customer segment in §2.5.2 and the existing customer segments in §2.5.3.

2.5.1 Optimal Technology Adoption Decision

The conditions for a dominant strategy for firm *i* is that $P_i(1,\varphi_j) > P_i(0,\varphi_j)$ for $\varphi_j = 0$ and $\varphi_j = 1$. Lost sales due to misfit reduce the firm's profit when it adds technology. We denote those lost sales as

$$R_i = a_{ii}\left[\Theta_i^* - \theta_n\right]^2 N_0 + b_{ii}\left[\Theta_i^* - \theta_j\right]^2 S_{j,0} + c_{ii}\left[\Theta_i^* - \theta_i\right]^2 S_{i,0}, \tag{2.15}$$

which identifies a *product-technology fit barrier* to be overcome by the firm adding technology. Adding technology must increase the firm's effectiveness (and thereby sales and profit) in adding sales by enough so that it can compensate for the product-technology fit barrier and redesign cost. Recall that if a given customer segment prefers one technology outcome over another, the firm's effectiveness for that segment increases for that preferred outcome. Formally,

Proposition 2.3: Adding technology is a dominant strategy for firm *i* if, for $\varphi_j = 0$ and $\varphi_j = 1$,

$$\begin{bmatrix} \left[\beta_i(1,\varphi_j) - \beta_i(0,\varphi_j)\right] N_0 + \\ \left[\rho_i(1,\varphi_j) - \rho_i(0,\varphi_j)\right] S_{j,0} + \\ \left[\rho_j(0,\varphi_j) - \rho_j(1,\varphi_j)\right] S_{i,0} \end{bmatrix} > R_i + \frac{D_i \Theta_i^{*2}}{\pi_i}. \tag{2.16}$$

From the left-hand side of Equation (2.16), we note that a firm does not necessarily increase sales for every customer segment when it adds technology; only the total must increase. Proposition 2.3 enables the firm to compare its gains in effectiveness, if any, (i.e., the left-hand side of Equation 2.16) to lost sales due to misfit (i.e., R_i) and how many sales it must add to compensate for redesign cost (i.e., the ratio of redesign cost to unit profit margin). To better analyze how a firm's capability for attracting, acquiring, and retaining customers affects its technology adoption decision, we next analyze two special cases of Equation (2.16). We describe sufficient conditions for which adding technology is a dominant strategy and discuss additional possible barriers to adding technology.

2.5.2 Optimal Technology Adoption Decision for Prospective Customers

Consider the technology adoption decision as it pertains to maximizing profit from prospective customers. The results of this subsection are good approximations to guide a firm's technology decision both when adding technology has negligible effect on the buying patterns of existing customers (e.g., the technology is only available as a promotion for new customers to convince them to buy, as for some smartphones) or when the product is so new that all customers are prospective (e.g., the firm is considering whether to add technology to their prototype of the product). We model this feature by setting acquisition effectiveness ($\rho_i(\varphi_i,\varphi_j)$ and $\rho_j(\varphi_i,\varphi_j)$) to be the same value regardless of technology decisions and by setting the impact of the product-technology fit on existing customers ($b_{ii},b_{ij},b_{ji},b_{jj}$ and $c_{ii},c_{ij},c_{ji},c_{jj}$) to zero. As a result, Proposition 2.3 provides conditions for a dominant strategy specifically for prospective customers when the product-technology fit in Equation (2.16) loses its dependence on existing customers. Formally,

Proposition 2.4: Adding technology is a dominant strategy for firm *i* if

(i) $\beta_i(1,1)-\beta_i(0,1)>\dfrac{R_i}{N_0}+\dfrac{D_i\Theta_i^{*2}}{\pi_i N_0}$; *and*

(ii) $\beta_i(1,0) - \beta_i(0,0) > \dfrac{R_i}{N_0} + \dfrac{D_i \Theta_i^{*2}}{\pi_i N_0}$.

The right-hand sides of both conditions in Proposition 2.4 are identical: the first term represents the proportion of prospective customers lost due to misfit divided by all prospective customers, while the second term is a ratio of the design cost to the maximum possible profit from prospective customers. If that right-hand side is equal to or greater than 1, then the firm should never add technology because there are not enough additional prospective customers to compensate for the new technology costs. From examining the conditions in Proposition 2.4(i)-(ii), we conclude that technology should not be added unless one of the outcomes from adding technology ($\{1,0\}$ or $\{1,1\}$) earns the maximum profit from prospective customers. Otherwise, one condition is violated and the firm might earn higher profits by maintaining the status quo. Similarly, not adding technology ($\{0,1\}$ or $\{0,0\}$) must minimize profits from prospective customers. Otherwise, the condition in either Proposition 2.4(i) or 2.4(ii) is violated. Interestingly, if the firm's attraction effectiveness is highest for diversification or standardization, the condition in Proposition 2.4(i) or 2.4(ii) is also violated. For instance, if the profits from prospective customers are highest for standardization, such that

$$\beta_i(1,1) > \beta_i(0,0) + \frac{R_i}{N_0} + \frac{D_i \Theta_i^{*2}}{\pi_i N_0} > \beta_i(1,0) > \beta_i(0,1) + \frac{R_i}{N_0} + \frac{D_i \Theta_i^{*2}}{\pi_i N_0}, \qquad (2.17)$$

the condition in 2.4(ii) will be violated. We view this as a *standardization barrier*.[12]

Proposition 2.4 thus displays the existence of *symmetric excess inertia,* as discussed by Farrell and Saloner (1986) and Belleflamme (1998). Each firm would prefer to add technology if it knew the other firm would, but both firms otherwise maintain the status quo. For their models, this occurred when the firms made sequential technology decisions with partial information. In our context, if the standardization barrier exists as in Equation (2.17) for both firms, symmetric excess inertia occurs even though both firms have common knowledge as they make their simultaneous decisions. If neither firm has a dominant strategy, there are either 0 or 2 regret-proof technology sets.[13] When there are 2 such sets, at least one firm may be able to increase profit if *both* change their technology adoption decision. The 2 sets are either standardization ({0,0} and {1,1}) or diversification ({0,1} and {1,0}). For instance, in Equation (2.17), if both firms have the same ordering of {1,1} followed by {0,0}, both would increase profits if standardization around adding technology had occurred. However, to do so would require a signaling or coordination mechanism on the part of at least one firm, which is outside the scope of our non-cooperative game.

2.5.3 Optimal Technology Adoption Decision for Existing Customers

Consider now the technology adoption decision as it pertains to maximizing profit from existing customers. The results of this subsection are good approximations to guide a firm's technology decision when adding technology has negligible effect on the buying patterns of prospective customers (e.g., the technology-enhanced product is only available to previous customers as a product upgrade, as with some software products). We model this by setting attraction effectiveness ($\beta_i(\varphi_i,\varphi_j)$ and $\beta_j(\varphi_i,\varphi_j)$) to be the same regardless of the technology decision and setting the effect of the product-technology fit on prospective customers (a_{ii}, a_{ij}, a_{ji}, and a_{jj}) to zero. As a result, As a result, Proposition 2.3 provides conditions for a dominant strategy specifically for existing customers if Equation (2.16) loses its dependence on prospective customers.

If the firm's acquisition of its rival's customers increases when that firm chooses to add technology, then its profit may increase whereas the rival's profit decreases. By symmetry, however, the firm's existing customers may have a higher preference for the rival's product when the firm adds technology. This would increase the rival's acquisition effectiveness, thereby decreasing the firm's profit. The technology preferences of the firm's existing customers can therefore be an obstacle to adding technology, even if adding technology increases that firm's acquisition. We view this as an *acquisition barrier*. However, it still is possible for both firms to overcome the barrier of their own customers even though they are involved in zero-sum competition for the existing customer segments. Formally,

Proposition 2.5: Both firms have a dominant strategy to add technology if

(i) $$\left[\rho_i(1,0)-\rho_i(0,0)\right]S_{j,0}+\left[\rho_j(0,0)-\rho_j(1,0)\right]S_{i,0} > R_i+\frac{D_i\Theta_i^{*2}}{\pi_i}; \textit{ and}$$

(ii) $$\left[\rho_i(1,1)-\rho_i(0,1)\right]S_{j,0}+\left[\rho_j(0,1)-\rho_j(1,1)\right]S_{i,0} > R_i+\frac{D_i\Theta_i^{*2}}{\pi_i}; \textit{ and}$$

(iii) $$\left[\rho_j(0,1)-\rho_j(0,0)\right]S_{i,0}+\left[\rho_i(0,0)-\rho_i(0,1)\right]S_{j,0} > R_j+\frac{D_j\Theta_j^{*2}}{\pi_j}; \textit{ and}$$

(iv) $$\left[\rho_j(1,1)-\rho_j(1,0)\right]S_{i,0}+\left[\rho_i(1,0)-\rho_i(1,1)\right]S_{j,0} > R_j+\frac{D_j\Theta_j^{*2}}{\pi_j}.$$

The first and second terms on the left-hand side of the conditions in Proposition 2.5(i)-(iv) indicate the change in a firm's acquisition and retention, respectively, given the change in effectiveness due to adding technology. The first term of the right-hand side indicates the lost existing sales (from both existing segments) due to misfit from adding technology, while the second term shows how many sales the firm must add in order to compensate for the redesign cost. Just as in Proposition 2.4, when the preferences for technology of either existing customer segments favor standardization or diversification, a condition will be violated. The conditions in Proposition 2.5(i)-(ii) guarantee that firm *i* adds technology because, regardless of the rival's technology decision, the firm will increase final sales by enough to compensate for the redesign cost, thus increasing total profit. Conditions in Proposition 2.5(iii)-(iv) guarantee the same for firm *j*. Table 2.4 uses the conditions in Proposition 2.5(i)-(iv) to illustrate how both firms depart from the status quo and standardize around adding technology.

Table 2.4. Nash equilibrium at {1,1} for Proposition 2.5

Firm *i* / Firm *j*	Firm *j* maintains the status quo ($\varphi_j = 0$)	Decision, Firm *j*	Firm *j* adds technology ($\varphi_j = 1$)
Firm *i* retains the status quo ($\varphi_i = 0$)	{0,0} → ↓	Condition (ii) means $P_j(0,1) > P_j(0,0)$ Firm *j* adds technology →	{0,1} ↓
Decision, Firm *i*	Condition (i) means $P_i(1,0) > P_i(0,0)$ Firm *i* adds technology ↓		Condition (iii) means $P_i(1,1) > P_i(0,1)$ Firm *i* adds technology ↓
Firm *i* adds technology ($\varphi_i = 1$)	{1,0} →	Condition (iv) means $P_j(1,1) > P_j(1,0)$ Firm *j* adds technology →	{1,1}

Recall that both firms maintain the status quo at {0,0} before making their decisions. Table 2.4 first shows that maintaining the status quo is not a Nash equilibrium because both firms can increase profit by being the only firm to add technology.

However, either firm would increase profit by also adding technology if the other firm has also done so. Because of this, each firm should add technology regardless of its rival's decision, and {1,1} is the technology outcome chosen. Note that according to the conditions, a firm may actually earn higher profits by standardization around the status quo rather than standardization around adding technology (e.g., if $P_i(1,0) > P_i(0,0) > P_i(1,1) > P_i(0,1)$). From an industry perspective, this example demonstrates that not all firms have to earn maximum profit for a given standardization in order for that standardization to be a Nash equilibrium.

A firm may still suffer a decrease in its effectiveness for an existing customer segment even if the conditions in Proposition 2.5(i)-(iv) are not violated. Specifically, one of the terms on the left-hand side of a condition in Proposition 2.5 could be negative. A firm may not be willing to add technology if it might suffer lost sales from a customer segment. We thus provide an example that, given the conditions in Proposition 2.5(i)-(iv), effectiveness values exist such that both firms can increase sales from both existing segments by adding technology.[14] If acquisition effectiveness for both firms is ordered as $\rho_i(1,0) > \{\rho_i(0,0), \rho_i(1,1)\} > \rho_i(0,1)$ and $\rho_j(0,1) > \{\rho_j(0,0), \rho_j(1,1)\} > \rho_j(1,0)$, and these improvements in effectiveness are large enough so that the conditions in Proposition 2.5(i)-(iv) are not violated, both firms always increase effectiveness for both existing customer segments when they add technology. To explain how this result works in practice, we draw a comparison from the well-known "Prisoner's Dilemma." According to the Nash equilibrium of the game, two prisoners confess to their crime because each prisoner will spend the most (least) years in prison if he is the only prisoner not to confess (to confess, respectively). In a similar fashion, both our firms add technology because their lowest acquisition effectiveness occurs when they are the only firm not to add technology, and their highest acquisition effectiveness occurs when they are the only firm to add technology.

Proposition 2.5 thus complements the work of Farrell and Saloner (1988) and Van Wegberg (2004), who suggest that both firms may still add technology even when there are no prospective customers. This is surprising because in a zero-sum setting, a change in technology outcome results in one firm being less profitable than before. As a result, it is *not* possible for standardization around adding technology to deliver the maximum profit for both firms. In fact, our example explaining how both firms could increase sales shows that standardizing around adding technology is at best the second most profitable technology outcome for a firm.

2.6 Conclusions

This paper focused on a firm's decision to add a technology that changes how customers interact with its product. We further contributed to previous research by segmenting customers into existing and prospective customer groups and extending the technology adoption decision to consider product redesign. We first explored the product redesign decision and how to minimize the level of misfit between the firm's product-technology fit and the ideal product-technology fit of each customer segment. We focused on what conditions for a customer segment or the firm's capabilities led the firm to shift its product-technology fit toward prospective customers, whose ideal fit tends toward radical innovation. For the decision on whether to add technology, we modeled the tradeoffs between increasing the firm's effectiveness (and hence sales and profits) when technology is added *and* decreasing profits due to misfit and product redesign cost. After providing general conditions that determine whether firms should add technology, we addressed two special cases to articulate the conditions under which a firm can overcome the standardization and acquisition barriers. Our analysis provides numerous insights to managers, which we articulate below.

Product redesign cost causes firms to under-invest in product-technology fit. We suggest that a firm never invest in a product-technology fit that exceeds the ideal product-technology fit of customers (Proposition 2.1a). However, a firm can invest in a fit below the minimum ideal fit level when the cost of product redesign is high relative to the unit profit margin. We therefore recommend that, due to product redesign cost, profit-maximizing firms should not fully satisfy their customers' ideal product-technology fit. This recommendation may partly explain why it took manufacturers so long to integrate PDA functions into cell phones even though PDAs and cell phones have both been around for decades and smartphones have sold well.

Radical innovation may be more prominent for low ratios of redesign cost to unit profit margin. Furthermore, despite competing for the same customers, the firm may aim for component innovation (Proposition 2.1c) while its rival pursues radical innovation. If the firm possesses excellent product development capabilities that can command high prices, it should strive for more radical innovation. This also enables it to attract more prospective customers, who are more numerous in the early stages of the product lifecycle. For example, Apple and Blackberry charge relatively high prices for their smartphones, but manage to release smartphones that display a high level of radical innovation.

Radical innovation may be more prominent if prospective customers are more likely to balk at purchasing if a product does not meet their ideal product-technology fit. In industries in which a dominant design has arrived, firms tend to focus on component innovation (Henderson and Clark, 1990). However, if prospective customers become more likely to balk at purchasing if their ideal fit is not met, the firm's optimal fit should increase to reduce losses due to product-technology misfit (Proposition 2.1a and sensitivity analysis). The same phenomenon occurs if the existing customer segment that is closest to prospective customers in ideal fit becomes more likely to recoil from purchasing due to a misfit (Proposition 2.2b). In practice, a firm that tends to attract many new customers, or that develops a reputation for easy-to-use, well-designed products, would see their customers' opinion shift toward greater product-technology fit. Our results indicate that the firm should take advantage of that shift to radically transform the product by adding technology. Apple, for instance, performed radical innovation by integrating touch screen and cell phone (e.g., no keypad) because it assumed that a highly integrated touch screen would attract more customers.

Standardization around adding technology may be less desirable when favored by customers. We introduced intuitive conditions that highlighted when a firm should add technology given its optimal product-technology fit. These conditions indicate that a firm should add technology if the additional customers now attracted to the product are more numerous than the number of customers who subsequently balk at purchasing because of misfit. In addition, enough new customers must be added to also compensate for the optimal product redesign cost (Propositions 2.3, 2.4, 2.5). However, a firm that sells to customers who prefer both firms to sell standardized products (with or without technology) will face a dilemma (Proposition 2.4). Standardizing around adding technology may be more profitable than the status quo, but what if the rival does not add technology and the firm is the only one to do so? In practice, we recommend that managers of such firms communicate with their rival regarding their technology adoption decision to avoid diversification. A smartphone manufacturer, for instance, would benefit from ensuring that it uses the same standard as its rival to maximize roaming area for customers.

In the absence of prospective customers, a firm and its rival may face a Prisoner's Dilemma. When there are no prospective customers in an industry, the firm's gain in customers is its rival's loss. Consequently, at equilibrium, firms may standardize around adding technology for the sake of avoiding the outcome where they earn their lowest profit rather than for the sake of maximizing their profit (Proposition 2.5). We thus recommend that in markets where firms emphasize repeat business (existing customers), a firm does not agree to standardization around adding technology, unless the technology is profitable even if it was the only firm to adopt it. This insight might help explain why Research in Motion, which has a strong base of repeat customers, waited for some time to follow Apple and release its own touch screen phone.

There are many opportunities for future research in modeling how customer preferences affect technology decisions. For instance, we recognize the recommendations from previous research that state that a firm's optimal decision may be to extend its product line over time and offer multiple versions if customer segments have differing preferences (e.g., Chen and Yu 2002, Wilson and Norton 1989). In our model, we assumed that the two firms may release only one version due to cost, design, compatibility, or legitimacy issues, and make a one-time decision on adding technology. We note that our model can be applied to a product line offering if the two product versions are targeted at mutually exclusive customer segments (prospective or existing). By solving the special cases in §2.5.2 and §2.5.3, a firm can determine if it should add technology for either product version. Modeling more complex product line offerings with cannibalization of the first product version is an opportunity for future work.

Research could also be done on modeling the likelihood of different segments to "comparison shop" before settling on one firm's product, or perhaps dropping out of the market altogether. For instance, one would think prospective customers would be less aware of what the rival had to offer than would an existing customer of either firm. Or, the model could be altered such that the impact of misfit on a segment's customers is directly contingent upon the product-technology fit of the other firm. More complex customer segmentation could be accomplished via finite mixture distribution theory, as in Bayus and Mehta (1995). Further, the model could be extended to better incorporate profit differences between prospective and existing customers (such as category growth or price discounts) and price elasticity.

Nevertheless, in the current article, the modeling features add to the body of research on customers' perspective on technology and engineering management, and on the relationship between technology adoption and product design. There is much to be done to further our understanding of the effects of customers, cost, and rivalry on firms' technology adoption decisions, and we hope that others join us in this effort.

Chapter 3

New Product Positioning for a Segmented Market

3.1 Introduction

When selecting a new product's quality and price, a firm must meet the customer segment(s) needs in order to convince them to purchase (Moorthy 1988, Moorthy and Png 1992). If the new product represents a significant technological advance over past offerings, the purchase decisions of customers will be affected by their opinions about technology. Rogers (2003) and Moore (2000) indicate that technologically-advanced products encounter customer segments whose priorities in making their purchase decisions may conflict with one another. For example, Rogers (2003) identifies five customer segments (innovators, early adopters, early majority, late majority, and laggards) for technologically-advanced products, each with different levels of *innovativeness.* He defines innovativeness as the degree to which the adopter accepts new ideas compared to others. Each segment specified by Rogers has different priorities in deciding whether to purchase a new, technologically-advanced product. The firm must thus decide which segment(s) it should pursue given the size of each segment, the priorities of each segment in making purchase decisions, and the firm's ability to meet each segment's priorities. If the product cannot attract any customer segment, then the launch will be a failure.

Besides attracting customer segments to the firm, the firm's quality and price decisions must also be optimal with respect to the competition. Even if a firm launches its product first (a *first mover*), a rival may appear (*late entrant*) and select a more profitable quality and price. For example, Apple initially beat IBM to market in the home computer industry, but IBM added a monitor to its package (thus increasing overall quality) and charged a higher price than Apple to cover its costs (Kim and Mauborgne 2005). The order of entry can be so critical to firms that they create fictional products and launch dates to keep other firms from launching a product before them, such as Nintendo's "vaporware" gaming system (Schilling 2008).

For a practical application of how customer segments differ and the dilemmas associated with order of entry, consider the brain-computer interface product produced by rivals OCZ Technology and Emotiv Systems. This product permits users to send signals to a computer via a headset that reads brain waves (Edwards 2008). A certain segment of potential customers is most interested in product performance on important tasks—that is, the product's quality. For example, a video-game reviewer enthusiastically notes that "The difference in reaction time…is great enough that…you will probably see an immediate improvement" (Lin 2008) and says the product is worth the relatively high price. Such a customer would fall into Rogers' (2003) *innovator* segment, which is composed of relatively wealthy lovers of technology willing to take risks on new products. They make purchase decisions based on the higher-quality product.

However, other customers will instead base their product purchase decision on its *net value* (product price relative to the value customers place on the product). For example, Lesco Rogers, a doctor interested in medical applications of the product, remarks that "What makes the technology interesting to me is the price point" (Singer 2008). Lesco's patients would fit Rogers' (2003) *early majority* or *late majority* segment, which must be sure that it is economically and practically advantageous to adopt.

Given these different segments, OCZ Technology, the first mover, must decide where to set product quality and price to maximize profits. As of June 2008, OCZ has decided to offer a relatively low price and product quality, whereas its rival, Emotiv, which will be launching its version in six months, has selected a more expensive version. Our research would assist both firms to make an optimal decision given the competition and customer segments they face.

The product design and marketing literature has investigated how established firms should set price and/or quality for customer segments. However, as outlined by Rogers (2003), Moore (2000), and others, the diffusion literature in general has failed to model the important differences in customer segments when the new product is technologically-advanced. If, as assumed by previous literature (e.g. Desai 2001), all customers are part of the early or late majority categories outlined above, the firm will neglect customers from the innovator segment. Moore (2000) identifies reaching both innovators and the early majority as the major factor in whether a technologically-advanced product launch will be successful or not and terms this as "crossing the chasm." We thus reduce Rogers' five categories to focus on two segments, an *innovator segment* which prefers high quality and a *mainstream segment* which prefers a high net value. This focus allows us to properly analyze the positioning of a new technologically-advanced product and thus ask, *given the priorities of both customer segments, how* *should competing profit-maximizing firms set the quality and price of a new technologically-advanced product to attract one or both customer segments?*

We model a closed-loop Stackelberg game in which a late entrant reacts to a first mover's product quality and price, but the first mover considers the potential of a late entrant when making its own decision. We assume that each firm selects its quality first and price second. If those quality and price levels meet or exceed a segment's requirements and the other firm's quality and price, the firm is able to attract a proportion of customers from that segment. The product launch is assumed to have failed if it cannot attract customers from either segment. After solving the game, we investigate whether a firm with a production cost advantage is better off as a first mover or a late entrant. At a time when globalization has increased both the speed at which a firm can launch a new product and the diversity of customer types, our research assists both pioneering and following firms and new ventures in selecting optimal product positions.

Our contribution to the literature is threefold. First, we adapt previous models of market segmentation to fit the literature on new technologically-advanced products. Our contribution in modeling customer segments also gives insight as to whether technologically-advanced products should be offered at a high price (to only attract the innovator segment) or low price (to attract both segments or the potentially larger mainstream segment). Second, we provide simple heuristics based on production cost as to how a first mover should protect itself against the threat of a late entrant. Third, we also confirm that higher profits for a first mover due to lower price and quality may make it easier for a late entrant to successfully compete for the innovator segment.

Section 3.2 reviews the pertinent literature on product line extensions and new product positioning, while §3.3 describes the model. Section 3.4 highlights the optimal price and quality for a first mover and late entrant, while §3.5 concludes by summarizing our findings and discussing management implications.

3.2 Background Literature

We examine the new product development literature on the challenges firms face in launching a new technologically-advanced product. We first review the market entry literature on the characteristics of both a first mover and a late entrant and of the customer segments themselves. We then examine the marketing literature on new product positioning and demonstrate how our work places previous models of new product launch in a new technologically-advanced product context.

Lieberman and Montgomery (1988) identify three potential advantages for the first mover. These advantages include technological leadership, whether it be in lower costs due to higher output or better product technology, and preemption of scarce assets, such as selecting the optimal product characteristic space. Fornell et al. (1985) also note that the market pioneer may have an advantage in product quality. Our model allows us to consider to what extent a first mover’s production costs, pricing, and quality can prevent a late entrant from gaining a market foothold. However, Lieberman and Montgomery (1988) indicate that a late entrant does have several advantages as well. The late entrant faces a lower level of technological or market-related uncertainty than the first mover. In addition, the first mover may be locked into its market position, allowing a late entrant to react to market trends more rapidly. Our work addresses these issues by studying whether production cost and marketing ability give the first mover an advantage over the late entrant.

A related field of research is what characteristics lead a new venture to become either a first mover or a late entrant. Lieberman and Montgomery (1988) identify this as a literature gap, and Robinson and Fornell (1991) answer this question through empirical study on market pioneers, early followers, and late entrants. They found that firms with superior finance skills tend to be market pioneers, firms with existing manufacturing skills tend to be early followers, and firms with superior marketing skills tend to be late entrants. Interestingly, a first mover does not benefit from using an existing brand name or goodwill; thus, a first mover's technological or marketing uncertainty is not affected by whether it is a start-up or an experienced firm. Thus, we also assume that there are no branding effects in the valuation each segment places on the products. We also contribute by investigating whether a firm with a production cost advantage relative to its rival would prefer to be a first mover or late entrant.

Robinson (1990) also examines how new product characteristics affect which firm attracts the larger market share. He found that if a firm's product has a relative advantage over its rival, it results in at least three to four extra percentage points of market share. However, a new, proprietary technology does not result in market share gains unless it can be proven to possess a comparative advantage. In addition, Robinson (1990) found that even if the product is incompatible with current customer behavior (i.e. a radical innovation that makes previous competency obsolete), it will not affect market share. Thus, our model focuses on the quality of the competing new products rather than the characteristics of the technology embedded in each product.

To examine past research on product competition, we review the marketing literature on new product positioning. Eliashberg and Jeuland (1986) investigate how a monopolist should change its prices over time when competition appears in the second period. However, their model does not study the effects of product quality. Key papers in new product positioning that consider both price and quality include Moorthy (1988) for the duopoly case and Moorthy and Png (1992) for a single seller attempting to match two products to two market segments without reducing profit. We follow their assumption that a firm selects its quality first and price second, and that those quality and price levels must meet or exceed customer requirements to attract a market segment. In their research, the two customer segments have different product valuations. We place this work in context for new technologically-advanced products by also letting the segments differ in priorities (quality compared to net value).

Subsequent work inspired by Moorthy (1988) and Moorthy and Png (1992) can be grouped into four areas: market modeling (assigning different preferences and structures to different market segments), minimizing cannibalization (which they define as a customer willing to pay for the high-priced product instead deciding that the low-priced product is sufficient for their needs), adding more complex cost structures (e.g. adding design costs), selecting the optimal time to introduce a new product. We focus on cannibalization and market modeling issues in the remainder of this review to show how our model contributes to the literature by applying a technologically-advanced product context to both the market segments and order of firm entry.

Further research on product cannibalization includes Wilson and Norton (1989), and Desai (2001). The work most closely related to our model is that of Desai (2001), who investigates how firms should design product lines. As in our model, products are judged by quality-type attributes on a “more is better” basis by all customers. Using high and low quality valuation segments that account for customer tastes, Desai addresses how companies could set product quality and price to avoid cannibalization. Desai found conditions under which a firm could match each product’s quality to each segment’s preferred quality level, or if necessary lower the quality of the lower-quality product. In our new technologically-advanced product context, we assume that due to financial, production, and marketing reasons, the firms can only release one product for the entire market. Thus the firm may suffer cannibalization if it wishes to attract both customer segments; the high-quality segment purchases a lower-quality (and lower price) product than if the product had only been designed for the high-quality segment. We improve on Desai’s model by having the two segments differ not only on their valuation of the product but also on the variables themselves that control the purchase decision (quality and net value).

Research in market modeling includes Kim and Chhajed (2002), who account for multiple quality-type attributes for a single product and allow two customer segments to assign different weights to each attribute. However, their model is for a monopolist, and net value controls a purchase decision for both segments. Schmidt and Dreuhl (2005) model variations in product attributes and costs and also rely on Rogers (2003) to determine customer groups. However, their focus is also on segmenting customers by net benefit or by reservation prices rather than by product quality. Thus, our work is the first to study a customer segment whose purchase decision is influenced by relative quality rather than relative net value.

For the sake of focusing on customer preferences, our model uses the relatively simple cost structure of Moorthy and Png (1992). Additional research on cost issues has also modeled design cost (Ramdas and Sawhney 2001) and advertising expenditures (Villas-Boas 2004), which we do not consider in our model. We focus instead on a more precise model of customer preferences than in the aforementioned research.

A certain class of models (e.g. Klastorin and Tsai 2004, Souza 2004) has focused on the optimal continuous time-to-market for new products. However, their work emphasizes the launch of several product versions (or new products altogether) over time, while we focus on how the initial, main version of the product should be launched. Instead of timing, we study the optimal order (first or second) for a firm's market entry.

3.3 Model Formulation

Consider a product that can be differentiated for all customers on an attribute that exhibits "more is better" characteristics. For our brain-computer interface product example in the introduction, that attribute would be the speed at which brain signals are converted into on-screen activity. Other examples of such attributes are hard drive capacity for a computer and screen resolution for a cell phone. For brevity, that attribute is referred to as *quality* and denoted *q*, where $q > 0$. We thus are assuming that for the product attribute under consideration, quality can be measured on a continuous scale (as in Moorthy 1988, Desai 2001). We assume the firm has already decided the basic product design, and thus we do not model design or research and development costs. The firm still must decide production quality and unit price, denoted *p*, where $p > 0$, in order to maximize its profit.

In introducing the model, we focus on Firm 1, the first mover, because the model for Firm 2, the late entrant, can be derived straightforwardly by symmetry. We first describe the two customer segments that comprise the market. We assume that the innovator segment contains T_0 potential customers, and the mainstream segment contains M_0 potential customers. We assume that for the products under consideration, the size (or, equivalently, proportion of each segment) of each segment can be known. This assumption is supported by Rogers (2003, p. 281), who estimates the proportions in which each segment is found, and Erickson (1983), who estimates total market size for a new product.

Because the products are new, it is unrealistic to assume that both firms could attract all customers in a given segment, even if the firm meets the priorities (i.e., constraints) of each segment. Firm 1's marketing ability (both advertising and word-of-mouth effects) to attract each segment is thus modeled by $a_1 \in (0,1)$ and $b_1 \in (0,1)$. We assume that in symmetric fashion Firm 2's marketing abilities are denoted by a_2 and b_2, and that the sum of both firms marketing ability for a given segment is not greater than one (e.g. $a_1 + a_2 \leq 1$). The marketing ability also depends on how much time each firm's product is for sale.

We model the sequence of events from Firm 1's planning of its product positioning to the completed launch of both Firm 1 and Firm 2's products when both are in direct competition for the market. The order of decision-making is that Firm 1 selects quality and price (in that order), followed by Firm 2 similarly selecting its quality and price. Customers from both segments then decide to purchase from the firm(s) that best matches their preferences. We thus implicitly assume that customers are patient enough to delay purchase until Firm 2's product is launched (or, equivalently, are able to return Firm 1's product) if Firm 2's product is superior to that of Firm 1.

To model competitive interaction, we employ a long-range perspective. Either Firm 1 (or Firm 2) is able to gain a foothold in the market and attract one (or both) segments, or the product fails and Firm 1 (or Firm 2) is forced to withdraw the product from the market. Specifically, either Firm 1 is successful in meeting the innovator segment's needs, and thus attracts a_1T_0 customers (or, similarly, meets the mainstream segment's needs and attracts b_1M_0 customers), or the firm does not attract any customers from that segment.

We now examine the constraints Firm 1 must meet in order to gain a foothold in the market. We assume that the segments are homogenous in their valuations (as in Desai 2001), and thus the mainstream segment places a valuation on the product's quality of $w_M > 0$, while the innovator segment's valuation is $w_T > 0$. We assume that because the innovator segment is wealthier (Rogers 2003) and places a high value on technology for its own sake, $w_T > w_M$. Because the products are new, we assume that brand effects do not exist, and so the value is not dependent on which firm is offering the product. The product of a segment's valuation multiplied by the product's quality represents their *reservation price*—the highest price each customer would be willing to pay for one unit of product. Thus, the valuations w_T and w_M serve to convert units of product quality into monetary units. We follow the designation of Moorthy (1988) and assume that the reservation price is linear in quality-- w_Tq_1 for the innovator segment and w_Mq_1 for the mainstream segment.

Each segment will not purchase from Firm 1 unless the product's price is less than or equal to their reservation price. This participation constraint (e.g. as in Moorthy and Png 1992) has a simple interpretation. To induce a segment to purchase, Firm 1 must either lower its price to match the segment's reservation price, increase the product's quality so that the customers believe the product is worth the price, or adjust both price and quality. The participation constraints have the same form for both firms:

$$w_T q_1 - p_1 \geq 0 \text{, and} \tag{3.1}$$

$$w_M q_1 - p_1 \geq 0 \text{.} \tag{3.2}$$

When making their choice between the products of both firms, the customer segments use different standards. We first consider the innovator segment. Because they are wealthy and able to use complex technologies, they are not as concerned about getting the best deal from either firm. Instead, they purchase the product that has the highest quality, as long as Constraint (3.1) still holds. For example, in the brain-computer interface example, video gamers would be willing to buy the most expensive version for sale as long as it gave them an edge over other video game players. The innovation's choice constraint is thus

$$q_1 \geq q_2 \text{.} \tag{3.3}$$

In contrast to innovative customers whose choice constraint focused on quality, mainstream customers, who have fewer resources (Rogers 2003) will make their decision based on which firm offers them the greatest net value. (Recall that net value for mainstream customers is measured as $w_M q_i - p_i$, where $i \in \{1, 2\}$). We thus write the choice constraint for mainstream customers as

$$w_M q_1 - p_1 \geq w_M q_2 - p_2 \text{.} \tag{3.4}$$

We retain the non-negativity constraint of (3.2) because the value to mainstream customers from Firm 2's product ($w_M q_2$) may be less than the price Firm 2 offers (e.g., $p_2 = w_T q_2$), thus making Constraint (3.2) more difficult to satisfy than Constraint (3.4). If the firm is able to meet all constraints of a segment, the segment is said to have been *attracted* by the firm.

Given the constraints that must be met to attract either segment, Firm 1 attempts to maximize profit P_1 from whichever segment(s) it can attract. Firm 1's goal is thus to set price and quality so that Firm 1 maximizes the difference between what each segment is willing to pay and its per-unit production costs. Firm 1's marginal production cost of supplying the product to either segment is $c_1(q_1)$, so that production cost increases as quality increases. The objective function it hopes to maximize is thus

$$\underset{q_1,\, p_1}{\text{Max}}\, P_1 = \underset{q_1,\, p_1}{\text{Max}} \left[p_1 - c_1(q_1) \right] [a_1 T_0 + b_1 M_0] \,. \tag{3.5}$$

This is a game because Firm 1's optimal decision-making is affected by Firm 2 via Constraints (3.3) and (3.4). If Firm 1 can select p_1 and q_1 so that Constraints 3.1-3.4 are met, it realizes sales of $a_1 T_0 + b_1 M_0$. However, if its choice of optimal price and quality can only satisfy Constraints 3.2 and 3.3, it only serves the innovator segment and realizes sales of $a_1 T_0$, and if its choice of optimal price and quality can only satisfy Constraints 3.4 and 3.5, it only serves the mainstream segment and realizes sales of $b_1 M_0$. We proceed to study which constraints a first mover and late entrant should satisfy in order to maximize profit.

3.4 Stackelberg Game

In this section, we investigate a Stackelberg game in which the first mover sets product quality and price and the late entrant reacts to the first mover's selection as a given in setting its own quality and price. We assume the cost structure detailed in Moorthy and Png (1992), so that cost increases at an increasing rate as quality increases. Firm 1's profit from one unit is thus $p_1 - c_1 q_1^2$, and the objective function is concave with respect to quality. We follow Moorthy (1988) and assume that the firms first select product quality and subsequently fix prices. To obtain a sub-game perfect equilibrium, we use the technique of backward induction (e.g., Dixit and Skeath 1999) and first solve for optimal price.

3.4.1 Late Entrant Response

We examine the so-called closed-loop equilibrium in which the first mover considers the reactions of a late entrant when making its decisions, and the late entrant subsequently optimizes its product price and quality based on the first mover's decision. We simplify the discussion of the late entrant's strategy by presenting a lemma that proves that a profit-maximizing first mover only has two choices for the price it should offer. The late entrant's optimal response to each of the possible prices (and resulting quality levels) is then presented.

Lemma 1. The first mover's optimal price p_1^* must be equal to the product valuation of either the innovator segment ($w_T q_1$) or the mainstream segment ($w_M q_1$). The first mover's optimal non-zero quality q_1^* will thus be equal to $w_i / h_1 c_1$, where

$i \in \{M, T\}$ and h_1 is the largest real number in the range $(1, 2]$ such that all first mover constraints are satisfied.

The price rationale for Lemma 1 is that in order to satisfy the participation constraints (3.1) and (3.2), the first mover must charge a price that is less than or equal to $w_T q_1$ (for the innovator segment) or $w_M q_1$ (for the mainstream segment). However, in order to maximize its profit, the firm should charge the highest possible price. Thus, it is optimal for the firm to leave a given segment with zero net value by charging them the exact product valuation, $w_T q_1$ or $w_M q_1$. A similar trade-off between maximizing unconstrained profit and meeting segment constraints yields the quality result.

The parameter h_1 is introduced to better characterize the optimal quality. It serves as a measure of the level of quality needed to satisfy constraints associated with each segment(s), and thus also the profit lost due to the need to satisfy constraints. To maximize profit, h_1 should be set to the highest value for which at least one segment's constraints (3.1 and 3.3 for the innovator segment, or 3.2 and 3.4 for the mainstream) are binding. Because the firm's unconstrained maximization of Equation (3.5) is equal to $q_1^* = w_i / 2c_1$, if Constraints (3.1)-(3.4) are satisfied for $h_1 = 2$, the first mover earns its highest possible profit. Following Moorthy and Png (1992), we term $q_1^* = w_i / 2c_1$, $i \in \{M, T\}$, as the *efficient quality* because the firm maximizes the difference between price and production cost.

The firm may need to deviate from its efficient quality level (and decrease profit) to meet Constraints (3.1)-(3.4). The upper bound on h_1 is 2 because increasing h_1 past 2 both decreases profit and makes it more difficult for the firm to satisfy the constraints. On the other hand, if at least one constraint in (3.1)-(3.4) is not satisfied for $h_1 = 2$, and the firm wishes to attract the affected segment, the firm must reduce h_1. This decision increases quality at the expense of profit, and the firm may reduce h_1 down to $h_1 = 1$ in order to bind the previously unsatisfied constraint. We denote $q_1^* = w_i / c_1$ as the *indifferent quality* (firm earns zero profit when $h_1 = 1$), and assume that firms will not enter a market unless they can earn positive profit; thus 1 is the lower bound for h_1.

We examine the late entrant's optimal response to each price in turn and then describe in section 3.4.2 how the first mover would make its decision knowing that a late entrant will appear. Suppose first that Firm 1 sets price to the innovator's segment reservation price $p_1^* = w_T q_1$ and quality to $q_1^* = w_T / h_1^{'} c_1$. (We use $h_1^{'}$ to denote the specific value of $h_1 \in (1, 2]$ that Firm 1 has selected). Firm 2's maximization problem becomes

$$\underset{q_2,\, p_2}{\text{Max}}\, P_2 = \underset{q_2,\, p_2}{\text{Max}} \left[p_2 - c_2 q_2^2 \right] [a_2 T_0 + b_2 M_0], \tag{3.6}$$

$$q_2 \geq w_T / h_1 c_1, \tag{3.7}$$

$$w_T q_2 - p_2 \geq 0 \text{, and} \tag{3.8}$$

$$w_M q_2 - p_2 \geq 0. \tag{3.9}$$

Thus, the late entrant must satisfy Constraints (3.7) and (3.8) to attract the innovator segment and Constraint (3.9) to attract the mainstream segment. (There is only one constraint for the mainstream segment because the participation and choice constraints are the same). Further, because the participation constraint (3.9) is more difficult to satisfy than (3.8), the late entrant cannot charge a price higher than $w_M q_2$ if it wishes to attract both segments. We consider which segment maximizes the late entrant's profit in Proposition 3.1.

Proposition 3.1: Given the first mover's price and quality are $p_1^* = w_T q_1$ and $q_1^* = \frac{w_T}{h_1^{'} c_1}$,

(i) If the late entrant possesses a cost disadvantage such that $c_2 \geq h_1^{'} c_1$, the late entrant should set price $p_2^* = w_M q_2$ and quality $q_2^* = \frac{w_M}{2c_2}$ to attract the mainstream segment.

(ii) If the late entrant possesses a cost advantage such that there is a real number $h_2^{'} \in (1,2]$ such that $c_2 = \frac{h_1^{'}}{h_2^{'}} c_1$, but $c_2 \geq \frac{w_M}{w_T} h_1^{'} c_1$,

a. and profits are higher than for the mainstream segment, so that

$$\frac{w_T^2}{w_M^2} \frac{4[h_2^{'} - 1]}{[h_2^{'}]^2} > \frac{b_2 M_0}{a_2 T_0}, \tag{3.10}$$

the late entrant should set price $p_2^* = w_T q_2$, and quality $q_2^* = \frac{w_T}{h_2^{'} c_2}$ to attract the innovator segment; *or*

b. the late entrant should set price and quality according to Proposition 3.1(i).

(iii) If the late entrant possesses a cost advantage such that there is a real number $k_2^{'} \in (1,2]$ so that $c_2 = \frac{w_M h_1^{'}}{w_T k_2^{'}} c_1$,

a. and profits are higher than for any one segment, so that

$$\frac{4[k_2^{'}-1]}{\left[k_2^{'}\right]^2} > \frac{b_2 M_0}{a_2 T_0 + b_2 M_0}, \text{ and } \frac{w_M^2\left[h_2^{'}\right]^2[k_2^{'}-1]}{w_T^2[h_2^{'}-1]\left[k_2^{'}\right]^2} > \frac{a_2 T_0}{a_2 T_0 + b_2 M_0}, \tag{3.11}$$

the late entrant should set price $p_2^* = w_M q_2$ and quality $q_2^* = \frac{w_M}{k_2^{'} c_2}$ to attract both segments; *or*

b. the late entrant should set price and quality to serve one segment according to Proposition 3.1(ii,a) and 3.1(ii,b).

Proposition 3.1(i) shows that if the late entrant has higher production costs for the same level of quality, the late entrant cannot compete with the first mover for the innovator segment. However, the late entrant may still be able to attract mainstream customers, because the first mover's higher quality also results in the first mover charging higher prices. Thus, by setting price equal to the reservation price of the mainstream customers in Constraint (3.9), the late entrant's optimal quality is its efficient quality. It targets the mainstream segment.

Proposition 3.1(ii) indicates that even if the late entrant's production costs are greater than the first mover's, the late entrant can match the quality level set by the first mover by lowering $h_2^{'}$ (and thus, its profits) to meet the cost condition. The late entrant must then select only one segment to attract. The decision is affected by production costs, the valuation chosen by each segment, and the level $h_1^{'}$ chosen by the first mover. If the first mover were more concerned with profit maximization than competition from the late entrant, $h_1^{'}$ will be set close to its upper bound, and the quality offered by the first mover will decrease. This makes it easier for the late entrant to compete for the innovator segment. However, for the late entrant to earn more profit from the innovator segment rather than the mainstream segment, the firm must be able to gain at least as many customers from the innovator segment as the mainstream segment ($a_2 T_0 \geq b_2 M_0$). Otherwise, because the left-hand-side of constraint (3.10) is larger than one for all values of $h_2^{'}$, the late entrant should set a lower price to attract the mainstream segment.

Proposition 3.1(iii) covers the unusual case in which the late entrant has a cost advantage so strong that it could attract both segments. Specifically, it could charge the low price desired by the mainstream segment and still offer a high enough product quality to induce the innovating segment to purchase. We note that this is most likely to occur when the first mover offers its efficient quality to the innovating segment and when the difference between the two segment's valuations of the product is small ($w_T \approx w_M$). However, due to the upper bound on $k_2^{'}$, the first condition in (3.11) requires that at least 75% of the sales from both segments are from the innovator segment. Thus, the late entrant may instead employ Condition (3.10) and settle for the most profitable segment.

We now consider the other case in Lemma 3.1, where the first mover has set a lower price of $w_M q_1$ and offers quality equal to $w_M / k_1^{'} c_1$, where $k_1^{'} \in (1, 2]$. The late entrant must decide which segment(s) to target given the following optimization problem:

$$\underset{q_2,\, p_2}{\text{Max}}\, P_2 = \underset{q_2,\, p_2}{\text{Max}} \left[p_2 - c_2 q_2^2 \right][a_2 T_0 + b_2 M_0] \tag{3.12}$$

$$q_2 \geq \frac{w_M}{k_1^{'} c_1} \tag{3.13}$$

$$w_T q_2 - p_2 \geq 0 \tag{3.14}$$

$$w_M q_2 - p_2 \geq 0 \tag{3.15}$$

Comparing Constraint (3.13) with Constraint (3.7), we can see if the valuations of both segments are far enough apart ($w_T > 2w_M$), Constraint (3.13) will always bind before Constraint (3.7). If so, then the late entrant can more easily attract both segments when the first mover targets the mainstream segment. We formally demonstrate this via Proposition 3.2.

Proposition 3.2: Given the first mover's price and quality are $p_1^* = w_M q_1$ and $q_1^* = \frac{w_M}{k_1' c_1}$, where $k_1' \in (1, 2]$,

(i) If the late entrant possesses a cost disadvantage such that $c_2 \geq \frac{w_T}{w_M} k_1 c_1$, the late entrant should set price $p_2^* = w_M q_2$ and quality $q_2^* = \frac{w_M}{2c_2}$ to attract the mainstream segment.

(ii) if the late entrant possesses a cost advantage such that a $h_2' \in (1, 2]$ exists so that $c_2 = \frac{w_T}{w_M} \frac{k_1'}{h_2'} c_1$, but $c_2 > k_1' c_1$,

a. and profits are higher so that

$$\left[\frac{w_T^2}{w_M^2} \right] \frac{4[h_2' - 1]}{[h_2']^2} > \frac{b_2 M_0}{a_2 T_0}, \tag{3.16}$$

the late entrant should set price $p_2^* = w_T q_2$ and quality $q_2^* = \frac{w_T}{h_2' c_2}$ to attract the innovator segment; *or*

b. the late entrant should set price and quality according to Proposition 3.2(i).

(iii) If the late entrant possesses a cost advantage such that a $k_2^{'} \in (1, 2]$ exists so that

$$c_2 = \frac{k_1^{'}}{k_2^{'}} c_1 ,$$

a. and profits are higher so that

$$\frac{4[k_2^{'} - 1]}{\left[k_2^{'}\right]^2} > \frac{b_2 M_0}{a_2 T_0 + b_2 M_0} \text{ and } \frac{w_M^2 \left[h_2^{'}\right]^2 [k_2^{'} - 1]}{w_T^2 [h_2^{'} - 1]\left[k_2^{'}\right]^2} > \frac{a_2 T_0}{a_2 T_0 + b_2 M_0} , \qquad (3.17)$$

the late entrant should set price $p_2^* = w_M q_2$ and quality $q_2^* = \frac{w_M}{k_2 c_2}$ to attract both segments; *or*

b. the late entrant should set price and quality to serve one segment according to Proposition 3.2(ii,a) and 3.2(ii.b).

Proposition 3.2(i) coupled with Proposition 3.1(i) indicate that late entrants cannot complete for the innovator segment when they have a significant cost disadvantage compared to the first mover. Their only option is to sell low-price, low-quality products to the mainstream segment. This result does not offer support or contradiction to the findings of Robinson and Fornell (1991). They reported that late entrants tended to have strong marketing skills; however, the proposition results does not depend on marketing ability (a_2 or b_2).

Proposition 3.2(ii) indicates that the late entrant can serve the innovator segment even if its costs are higher than those of the first mover, as long as it can gain more profit from that segment. We note that a lesser cost advantage is needed in Proposition 3.2(ii) than in Proposition 3.1(ii). Therefore, it is easier for the late entrant to attract the innovator segment when the first mover sets its price to target the mainstream segment. Proposition 3.1(iii) and Proposition 3.2(iii) also indicate that it is easier for the late entrant to attract customers from both segments when the first mover sets its price to target the mainstream segment. The rationale is that it is easier for the late entrant to have better quality than the first mover (and thus attract the innovator segment) when the first mover sets the lower price (and thus, quality) for the mainstream segment.

3.4.2 First Mover Solution

We now examine what the first mover's strategy should be in light of the results in Section 3.4.1. To simplify our recommendations, we focus on how production costs influence the options available to the first mover. As a result, we can make simple recommendations for the first mover based only on the ratio of production costs between the first mover and late entrant. We also assume that the first mover will not select a price and quality set which potentially will result in negative profit due to the late entrant's decision. We first examine extreme situations in which one firm has a significant cost advantage over the other, and subsequently the more likely situation where the firms have similar production costs. After analyzing each situation, we investigate whether a firm with a cost advantage would prefer to be the first mover or the late entrant.

Suppose the first mover has a strong cost advantage such that $c_1 = \frac{2w_M c_2}{w_T k_1^{'}}$ for some $k_1^{'} \in (1,2]$. This cost advantage is comparable to Proposition 3.1(iii) for the late entrant. The first mover can then attract both segments by setting $p_1^* = w_M q_1$ and quality $q_1^* = \frac{w_M}{k_1^{'} c_1}$, if

$$\frac{4[k_1^{'}-1]}{\left[k_1^{'}\right]^2} > \frac{b_2 M_0}{a_2 T_0 + b_2 M_0}, \text{ and } \frac{4w_M^2[k_1^{'}-1]}{w_T^2\left[k_1^{'}\right]^2} > \frac{a_2 T_0}{a_2 T_0 + b_2 M_0}. \tag{3.18}$$

Comparing our result to similar outcomes in Proposition 3.1(iii) and 3.2(iii), we see that the firm with a significant cost advantage may not increase profit if it is a first mover. The problem is that if the firm moves first, the late entrant may respond with $p_2^* = w_T q_2$, and thus the first mover must take the stricter production cost constraint from Proposition 3.1(iii) (rather than the more easily satisfied constraint in Proposition 3.2(iii)). However, the advantage of the first mover is that the late entrant must match whatever quality the first mover sets to attract the innovator segment. Thus, Condition (3.18) may be more likely to hold than Condition (3.17). Regardless of the first mover's choice, the late entrant will settle for the mainstream segment with $p_2^* = w_M q_2$ and $q_2^* = \frac{w_M}{2c_2}$. In similar fashion, if the first mover has a cost disadvantage such that $c_1 \geq \frac{w_T}{w_M} 2c_2$, the first mover settles for the mainstream segment while the late entrant is able to select the most profitable segment (or both segments).

We subsequently consider a case where the differences between production costs are such that the first mover's production cost is at most half (or twice) that of the late entrant. We consider how the first mover's strategy changes depending on whether the first mover's production cost is greater or less than the late entrant, and then determine if the firm with a production cost advantage is better off as a first mover.

Proposition 3.3 explains how the first mover's technology strategy changes as production cost c_1 increases:

Proposition 3.3: If $\frac{c_2}{2} \le c_1 \le c_2$,

(i) the first mover should set $p_1^* = w_T q_1$ and quality $q_1^* = \frac{w_T}{2c_1}$ to attract the innovator segment if

$$\frac{w_T^2}{w_M^2} > \frac{b_1 M_0}{a_1 T_0};\ or \qquad (3.19)$$

(ii) the first mover should set $p_1^* = w_M q_1$ and quality $q_1^* = \frac{w_M}{2c_1}$ to attract the mainstream segment.

Proposition 3.3(i) demonstrates that as long as the first mover has a cost advantage, its efficient (and lowest) quality level is sufficient to attract the innovator segment. At best, it is optimal for the late entrant to match the first mover's quality. Thus, the first mover will meet all constraints of the innovator segment without needing to increase quality (and decrease profit). Similarly, Proposition 3.3(ii) indicates that the first mover's efficient quality is sufficient to attract the mainstream segment. Finally, Condition 3.19 indicates that the first mover would always prefer to set price and quality for the innovator segment if the number of sales from both segments was the same.

We offer the complimentary case where the first mover is at a cost disadvantage when compared to the late entrant.

Proposition 3.4: If $c_2 < c_1 < 2c_2$,

(i) the first mover should set $p_1^* = w_T q_1$ and quality $q_1^* = \frac{w_T}{k_1' c_1}$ for some $k_1' \in (1, 2]$ to attract the innovator segment if

$$\frac{w_T^2}{w_M^2}\frac{4[k_1^{'}-1]}{[k_1^{'}]^2} \geq \frac{b_1 M_0}{a_1 T_0}\text{; } or \tag{3.20}$$

(ii) the first mover should set $p_1^* = w_M q_1$ and quality $q_1^* = \frac{w_M}{2c_1}$ to attract the mainstream segment.

Proposition 3.4(i) indicates that because the first mover is at a cost disadvantage, its efficient quality may not match the quality of the late entrant. In comparing (3.19) to (3.20), the first mover is less likely to attract the innovator segment in Condition (3.20) because $k_1^{'}$ is at most two (and thus Proposition 3.4(ii) applies). According to Propositions 3.3 and 3.4, the first mover must increase quality (and price) for the innovator segment as its production cost advantage decreases. However, for the cost range specified in Propositions 3.3 and 3.4, the first mover will set the same optimal price and quality for the mainstream segment regardless of its cost relative to the late entrant.

We conclude this section by contributing to the literature on which characteristics tend to be optimal for a first mover and late entrant.

Proposition 3.5: If $\frac{c_2}{2} \leq c_1 \leq c_2$, Firm 1 would prefer to be the first mover.

See appendix for complete proof. The rationale is that according to Proposition 3.3, Firm 1 as the first mover with a cost advantage is able to select its efficient quality for either segment. Since there is a case in Proposition 3.1 where a late entrant is unable to select the efficient quality for the innovator segment, then Firm 1 will always make more profit as the first mover. However, for the given cost range, if Firm 1 attracts only the mainstream segment, it does not matter if Firm 1 is a first mover or a late entrant. In either case the efficient quality will be optimal.

3.5 Conclusions

This essay examined the rivalry between two firms launching a new, technologically-advanced product in sequential order. They sell to a market split between innovator customers willing to pay a high price for the highest quality product and mainstream customers who just want to make sure to get their money's worth for the product's quality and price. We considered a Stackelberg game and solved for a closed-loop equilibrium. We were able to derive relatively simple conditions to guide decision-making that depended primarily on each firm's production cost and the amount of quality (and profit) a firm was willing to add for the sake of attracting the innovator segment.

Our key modeling contribution was to consider how the technologically advanced context of the game changes the conditions under which this game has previously been modeled. Specifically, our innovator segment contributed a new understanding of customer behavior due to the Technology Adoption Life Cycle model by Rogers (2003) and Moore (2000). In addition, we were able to analyze in what order a firm would prefer to enter the market if it has a production cost advantage, and also which type of first-mover pricing and quality is most profitable to the late entrant. We summarize the findings of our analysis next.

If the firm's cost advantage is large enough, it can attract customers from both segments regardless of the order of market entry (Propositions 3.1(iii) and 3.2(iii)). The firm prices its product low enough to attract the mainstream segment (and thus cannibalizing potential profits from the innovator segment), and sets the quality to be equal or higher to that offered by the rival so as to attract the innovator segment. Thus, products that exceed the innovative customers' expectations of quality for firms in the industry will be purchased by them even though the products are priced to fit the mainstream customer segment. We apply these findings to the price and quality points described by Hamilton (2008) for the firms selling brain-computer interface product. OCZ Technology, the first mover (July 2008), has decided to sell its product at a lower price and quality point ($149, three electrodes) than its competitor, Emotiv Systems (December 2008, $299, 16 electrodes). However, if OCZ can also improve its quality, it could compete for the innovator segment.

If the firm's minimum optimal quality is sufficient to attract the innovator segment and the innovator segment provides at least as many sales units as the mainstream segment, the firm should always prefer the innovator segment (Propositions 3.1(ii), 3.2(ii), 3.3(i), and 3.4(i)). This strategy is a best fit for niche products that will appeal to only a small fraction of mainstream customers, such as the video-gamer market for the brain-computer interface product in the introduction. Otherwise, the optimal price and quality depend on the number of sales in each segment, the difference in each segment's valuation of product quality, and the difference in each firm's production cost.

If the firm has a higher production cost than its rival, its quality must be greater than the rival's minimum optimal quality to reach the innovator segment (Proposition 3.4). The first mover that has higher production cost will be forced to set quality higher than the efficient level to match the late entrant's efficient quality for the innovator segment. However, production cost does not matter in setting price and quality to attract the mainstream segment. For example, it is possible that OCZ Technologies set their low price to target the mainstream segment because the production cost was too expensive to match the quality of Emotiv Systems, or that the mainstream segment sales available at the $149 price point are more than double those of the innovator segment sales.

If the firm has a lower production cost than its rival but can only serve one segment, it will increase profit by being the first mover (Proposition 3.5). For our model, when production costs are such that each firm's production cost is at least half of its rival's, the firm's profit is affected by order of entry (Proposition 3.5). Our result thus provides theoretical validation for Robinson and Fornell's (1991) empirical findings that first movers or early entrants have higher manufacturing and finance skill levels. The first mover with a production cost advantage is able to select the more profitable segment for itself and select an efficient quality (Proposition 3.3(i)).

If the firm has a lower production cost than its rival but may be able to serve both segments, it may not increase profit by being the first mover. The firm's advantage in going first is that it can set quality at a lower level and still attract the innovator segment, thus increasing profit. If the firm has a much lower production cost than its rival, it may also be able to reach the innovator segment by setting a low price to attract the mainstream segment. However, the problem is that for certain production cost ranges, the first mover cannot be sure whether the late entrant will set a high price and quality (thus making it more difficult to reach the innovator segment with a low price) or not. Thus, for example both Emotiv Systems and OCZ Technology may face increased competition if a large device manufacturer like Logitech enters the market. Logitech may be waiting until it is clear whether Emotiv Systems and OCZ Technology are high or low quality.

We conclude by evaluating the limitations of our model. We assume that customers will not favor the first mover just because their product is out first. However, because OCZ Technology has a 6-month head start on Emotiv Systems, the innovator segment may impatiently purchase from OCZ Technology rather than waiting for the higher-quality product from Emotiv Systems. Thus, changing the objective of our model is an area for future research. In addition, as currently constructed, a customer segment either purchases or does not purchase the product. A model could be constructed where quality and price have a more nuanced effect on demand. In addition, in this model there is no time dimension, and thus the first mover is certain of when the late entrant will arrive. A model where the exact period in which the late entrant's entrance is random or is triggered by certain events (e.g., late entrant enters and targets the mainstream segment if the first mover cannot meet the mainstream segment's constraints) would make the model applicable to more business scenarios. We look forward to further study of issues related to new product positioning in segmented markets, and hope others will join us in this effort.

Appendix to Chapter 1

A.1.1 Single-Period Model Set-Up

New venture i must select expenditure levels that solve

$$P_i = \underset{a_i, w_i}{\text{Max}}\ \pi_i S_i - a_i - w_i$$

with $S_i = S_i^0 + \rho_i f_i(a_i) S_j^0 - \rho_j f_j(a_j) S_i^0 + \beta_i g_i(w_i)[m - S_i^0 - S_j^0] - [1-\delta_i] S_i^0$. (A1.1)

The decision variables in (A1.1) are assumed to be such that $\rho_i f_i(a_i) < \delta_i$ and $\beta_i g_i(w_i) + \beta_j g_j(w_j) < 1$. Otherwise, a new venture has either acquired all of its rival's sales ($S_j = 0$) or attracted all unrealized sales ($S_i + S_j = m$). Given our assumption that the constraints are not binding, optimal expenditures are obtained by using the first-order conditions on the objective function with respect to expenditures. The second-order conditions for optimality are met (and there exists a unique optimal solution) if f_i and g_i are strictly concave in their respective parameter. This holds because negative second order derivatives and $\partial^2 f_i(a_i) / \partial w_i \partial a_i = \partial^2 g_i(w_i) / \partial a_i \partial w_i = 0$ yield a negative definite Hessian. These conditions result in diminishing returns from the expenditure variables.

A.1.2 Multi-Period Model Set-Up

A differential game is the appropriate solution method for an open-loop Nash equilibrium in an optimal control problem. Using Pontryagin's maximum principle, we maximize the Hamiltonian for new venture i as given by

$$H_i(t) = \pi_i S_i(t) - a_i(t) - w_i(t) + \lambda_i(t) \dot{S}_i(t) + \varphi_i(t) \dot{S}_j(t), \tag{A1.2}$$

with boundary equations $\lambda_i(T) = r_i$ and $\varphi_i(T) = 0$. The immediate profit of the new venture is $\pi_i S_i(t) - a_i(t) - w_i(t)$, the same as in the single-period case. However, we must now also consider the time remaining until the end of the planning horizon and the possibility that the new venture's current sales may be acquired by its rival. The future value of a sales unit to new venture i is $\lambda_i(t) \dot{S}_i(t) + \varphi_i(t) \dot{S}_j(t)$, where co-state variable $\lambda_i(t)$ measures the future value of one additional sales unit from new venture i and co-state variable $\varphi_i(t)$ measures the future value of one additional sales unit for new venture j. Solving the necessary conditions for the Hamiltonian with respect to the control variables yields optimal expenditures

$$a_i^*(t) = \left[\left[\lambda_i(t) - \varphi_i(t)\right] \rho_i S_j(t)[1-\gamma_i]\right]^{\frac{1}{\gamma_i}} \text{ and} \tag{A1.3}$$

$$w_i^*(t) = \left[\lambda_i(t) \beta_i [m - S_i(t) - S_j(t)][1-\theta_i]\right]^{\frac{1}{\theta_i}}. \tag{A1.4}$$

We note that the optimal decision variables in the single-period and multi-period models are nearly identical except for the unit profit margin. Profit is now a function of sales' future value over time rather than the fixed unit profit margin π_i. In Equation (A1.3), the unit profit margin for the rival's sales is the difference in future profit from new venture i possessing a sale and its rival possessing that sale ($\lambda_i(t)$-$\varphi_i(t)$). In contrast, the unit profit margin for unrealized sales in Equation (A1.4) only includes the future profit for new venture *i* (because an unrealized customer is worthless to the new venture before being realized). A closed-form solution for the control variables, which are affected by future sales values, requires a closed-form solution for the co-state variables. However, the co-state variables cannot be solved in closed form.

Appendix to Chapter 2

A.2.1 Solving the second stage. We can solve for the product-technology fit via the first order condition. Formally,

$$\frac{dP_i}{d\Theta_i} = -\pi_i\left[\left[a_{ii}N_0 + b_{ii}S_{j,0} + c_{ii}S_{i,0}\right]\Theta_i + \left[a_{ii}\theta_n N_0 + b_{ii}\theta_j S_{j,0} + c_{ii}\theta_i S_{i,0}\right]\right] - D_i\Theta_i = 0 \quad \text{(A2.1)}$$

if and only if $\Theta_i^* = \frac{\left[a_{ii}\theta_n N_0 + b_{ii}\theta_j S_{j,0} + c_{ii}\theta_i S_{i,0}\right]}{\left[a_{ii}N_0 + b_{ii}S_{j,0} + c_{ii}S_{i,0}\right] + D_i / \pi_i}$. This result holds if the second order conditions for optimality are met (and there exists a unique optimal solution) and thus the profit function is concave with respect to Θ_i. The second order derivative is

$$\frac{\partial^2 P_i}{\partial^2\Theta_i} = -\pi_i\left[a_{ii}N_0 + b_{ii}S_{j,0} + c_{ii}S_{i,0}\right] - D_i, \quad \text{(A2.2)}$$

and thus we have a unique optimal solution.

A.2.2 Proof of Proposition 2.1. The results are derived by substituting the optimal product-technology fit from Equation (2.11) into the inequalities $\theta_n - \Theta_i^* > 0$, $\theta_i - \Theta_i^* > 0$, and $\theta_j - \Theta_i^* > 0$. Thus, for Proposition 2.1(a), $\theta_n - \Theta_i^* > 0$ simplifies to

$$[\theta_n - \theta_i]c_{ii}S_{i,0} + [\theta_n - \theta_j]b_{ii}S_{j,0} + \theta_n D_i / \pi_i > 0, \quad \text{(A2.3)}$$

and since $\theta_n > \theta_i > \theta_j$, this condition always holds.

For Proposition 2.1(b), $\theta_i - \Theta_i^* > 0$ simplifies to $[\theta_i - \theta_n]a_{ii}N_0 + [\theta_i - \theta_j]b_{ii}S_{j,0} + \theta_i D_i / \pi_i > 0$, and for Proposition 2.1(c), $\theta_j - \Theta_i^* > 0$ simplifies to $[\theta_j - \theta_n]a_{ii}N_0 + [\theta_j - \theta_i]c_{ii}S_{i,0} + \theta_j D_i / \pi_i > 0$.

A.2.3 Proof of Proposition 2.2. The results are derived by taking the derivative of each parameter with respect to Θ_i^*. We provide Proposition 2.2(a) as an example. Specifically, $\frac{\partial\Theta_i^*}{\partial b_{ii}} > 0$ if $\frac{[\theta_i - \theta_n]a_{ii}N_0 + [\theta_i - \theta_j]b_{ii}S_{j,0} + \theta_i D_i / \pi_i}{\left[a_{ii}N_0 + b_{ii}S_{j,0} + c_{ii}S_{i,0} + D_i / \pi_i\right]^2} > 0$, and since the denominator is positive, $\frac{\partial\Theta_i^*}{\partial b_{ii}} > 0$ if

$$[\theta_i - \theta_n]a_{ii}N_0 + [\theta_i - \theta_j]b_{ii}S_{j,0} + \theta_i D_i / \pi_i > 0. \quad \text{(A2.4)}$$

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A.2.4 Proof of Proposition 2.3. Technology should only be added if the firm will increase profit.

Thus, it must be true that for $\varphi_j = 0$ and $\varphi_j = 1$, $P_i(1,\varphi_j) > P_i(0,\varphi_j)$. Substituting from Equation (2.14), $P_i(1,\varphi_j) > P_i(0,\varphi_j)$ becomes

$$\begin{bmatrix} \left[\beta_i(1,\varphi_j) + f_i(1,\varphi_j,\Theta_i^*,\Theta_j^*)\right]N_0 \\ +\left[\rho_i(1,\varphi_j) + g_i(1,\varphi_j,\Theta_i^*,\Theta_j^*)\right]S_{j,0} \\ +\left[1-\rho_j(1,\varphi_j) - h_i(1,\varphi_j,\Theta_i^*,\Theta_j^*)\right]S_{i,0} \end{bmatrix} - \frac{D_i\Theta_i^{*2}}{\pi_i} > \begin{bmatrix} \left[\beta_i(0,\varphi_j) + f_i(0,\varphi_j,\Theta_i^*,\Theta_j^*)\right]N_0 \\ +\left[\rho_i(0,\varphi_j) + g_i(0,\varphi_j,\Theta_i^*,\Theta_j^*)\right]S_{j,0} \\ +\left[1-\rho_j(0,\varphi_j) - h_i(0,\varphi_j,\Theta_i^*,\Theta_j^*)\right]S_{i,0} \end{bmatrix}$$

Rearranging terms, we have

$$\begin{bmatrix} \left[\beta_i(1,\varphi_j) - \beta_i(0,\varphi_j)\right]N_0 + \\ \left[\rho_i(1,\varphi_j) - \rho_i(0,\varphi_j)\right]S_{j,0} + \\ \left[\rho_j(0,\varphi_j) - \rho_j(1,\varphi_j)\right]S_{i,0} \end{bmatrix} > \begin{bmatrix} \left[f_i(0,\varphi_j,\Theta_i^*,\Theta_j^*) - f_i(1,\varphi_j,\Theta_i^*,\Theta_j^*)\right]N_0 \\ +\left[g_i(0,\varphi_j,\Theta_i^*,\Theta_j^*) - g_i(1,\varphi_j,\Theta_i^*,\Theta_j^*)\right]S_{j,0} \\ +\left[h_i(1,\varphi_j,\Theta_i^*,\Theta_j^*) - h_i(0,\varphi_j,\Theta_i^*,\Theta_j^*)\right]S_{i,0} \end{bmatrix} + \frac{D_i\Theta_i^{*2}}{\pi_i}$$

Substituting in the optimal values for fit from Equations (2.3), (2.6), (2.8), (2.11), and (2.14), we have

$$\begin{bmatrix} \left[\beta_i(1,\varphi_j) - \beta_i(0,\varphi_j)\right]N_0 + \\ \left[\rho_i(1,\varphi_j) - \rho_i(0,\varphi_j)\right]S_{j,0} + \\ \left[\rho_j(0,\varphi_j) - \rho_j(1,\varphi_j)\right]S_{i,0} \end{bmatrix} > R_i + \frac{D_i\Theta_i^{*2}}{\pi_i} \qquad \text{(A2.5)}$$

as in Equation (2.16).

A.2.5 Proof of Propositions 2.4 and 2.5. See Proposition 2.3.

Appendix to Chapter 3

A.3.1 Proof of Lemma 1. The Lagrangean and the Karush-Kuhn Tucker conditions are:

$$\begin{aligned} L_2(p_2,q_2) = {} & \left[p_2 - c_2q_2^2\right][a_2T_0 + b_2M_0] + \\ & \lambda_2[q_2 - q_1] + \mu_2[w_Rq_2 - p_2] + \theta_2[w_Mq_2 - p_2 - w_Mq_1 + p_1] + \gamma_2[w_Mq_2 - p_2] \end{aligned} \qquad \text{(A3.1)}$$

$$\frac{\partial L_2}{\partial p_2} = [a_2T_0 + b_2M_0] - \mu_2 - \theta_2 - \gamma_2 = 0$$

$$\frac{\partial L_2}{\partial q_2} = -2c_2q_2[a_2T_0 + b_2M_0] + \lambda_2 + \mu_2w_T + [\theta_2 + \gamma_2]w_m = 0$$

$$\lambda_2[q_2 - q_1] = 0$$

$$\mu_2(w_Rq_2 - p_2) = 0$$

$$\theta_2(w_Mq_2 - p_2 - w_Mq_1 + p_1) = 0$$

$$\gamma_2(w_Mq_2 - p_2) = 0$$

$$\lambda_2, \mu_2, \theta_2 \geq 0$$

$$q_2, p_2 > 0$$

We first solve for price. To satisfy the Lagrangian first-order condition with respect to price, one of the Lagrangian multipliers μ_2, θ_2, or γ_2 must be equal to zero. Thus the potential profit-maximizing prices are $p_2 = w_R q_2$, $p_2 = w_M q_2$, and $p_2 = p_1 + w_M[q_2 - q_1]$.

For $p_2 = w_M q_2$, it is necessary that $\mu_2 = 0$ and $\gamma_2 > 0$. There are four possible sets for the values of θ_2 and λ_2 (both are zero, both are positive, and one of each is zero and positive). We found that for the sets where $\lambda_2 = 0$, $q_2^* = w_M / 2c_2$, and for the other sets where $\lambda_2 > 0$, $q_2^* = q_1$ up to the point where $q_1 = w_M / c_2$ (increasing q_2^* further would result in negative profit). Similarly, when $p_2 = w_R q_2$, Firm 2's feasible solutions consist of setting $q_2^* = w_T / 2c_2$ or setting $q_2^* = q_1$ up to the point where $q_1 = w_T / c_2$.

We proceed to show if Firm 1 selects optimal price and quality, $p_2 = p_1 + w_M[q_2 - q_1]$ will never maximize profit unless $p_2 = w_R q_2$ or $p_2 = w_M q_2$. Suppose that $p_1 > w_M q_1$. If so, then Firm 1 will not be able to serve the mainstream segment, and the only feasible choice for Firm 1 is that $p_1 = w_T q_1$ and $q_1 = Max[w_T / 2c_1, q_2]$. If $q_1 = q_2$, then $p_2 = w_T q_2$. If $q_1 = w_T / 2c_1$, then $p_2 = \frac{[w_T - w_M]w_T}{2c_1} + w_M q_2$. We proceed to show that this price must also be equal to $w_T q_2$.

Such a price is too high to attract the mainstream segment, and thus the price must be set to $p_2 \le w_T q_2$ to attract the innovator segment. However, if $\frac{[w_T - w_M]w_T}{2c_1} + w_M q_2 < w_T q_2$, the price $\frac{[w_T - w_M]w_T}{2c_1} + w_M q_2$ is no longer profit-maximizing. Thus $p_2 = w_T q_2$ when $p_1 > w_M q_1$. Suppose instead that $p_1 = w_M q_1$; then $p_2 = w_M q_2$. Finally, suppose that $p_1 < w_M q_1$ (and thus $q_1 < w_M / 2c_1$), which results in $p_2 < w_M q_2$. However, this could not be an equilibrium, because Firm 2 will maximize profit by matching the net value of Firm 1, and Firm 1 increases profit from the mainstream segment by increasing price as long as $p_1 \le w_M q_1$. Thus, $p_1 < w_M q_1$ is not an optimal price for Firm 1, and $p_2 = p_1 + w_M[q_2 - q_1]$ thus must always be equal to $p_2 = w_M q_2$ or $p_2 = w_T q_2$.

A.3.2 Proof of Proposition 3.1.

Proof of Proposition 3.1(i). If Firm 2 is unable to match Firm 1's quality when $p_2^* = w_T q_2$, then it cannot attract the innovator segment. This is true if $q_2 = \frac{w_T}{h_2' c_2}$ is less than q_1^*, and Lemma 1 fixes $h_2' \in (1,2]$. The resulting condition is $h_1' c_1 < h_2' c_2$, and thus Firm 2 earns no profit if $p_2^* = w_T q_2$. Firm 2's only choice of price (via Lemma 1) is thus $p_2^* = w_M q_2$, which fulfills all constraints for the mainstream segment. Thus, Firm 2 may maximize its unconstrained objective function with respect to quality, and $q_2^* = \frac{w_M}{2c_2}$.

Proof of Proposition 3.1(ii). Suppose Firm 2 offers price $p_2^* = w_T q_2$ and instead is able to match Firm 1's quality. For this to be feasible, it must be true that $h_1^{'} c_1 \geq h_2^{'} c_2$ for $h_2^{'} \in (1,2]$ and $h_1^{'} \in (1,2]$. Firm 2's total profit is thus

$$P_2 = \left[\frac{w_T^2}{h_2^{'} c_2} - \frac{w_T^2}{[h_2^{'}]^2 c_2} \right] a_2 T_0 . \qquad \text{(A3.2)}$$

If, instead, Firm 2 offers price $p_2^* = w_M q_2$, the cost advantage is not large enough to attract the innovator segment. Thus, Firm 2 will set quality to $q_2^* = \frac{w_M}{2c_2}$ and profit is thus

$$P_2 = \left[\frac{w_M^2}{4c_2} \right] b_2 M_0 . \qquad \text{(A3.3)}$$

Comparing profits from each segment leads to

$$\frac{w_T^2}{w_M^2} \frac{4[h_2^{'} - 1]}{[h_2^{'}]^2} > \frac{b_2 M_0}{a_2 T_0} \qquad \text{(A3.4)}$$

for the innovator segment to be more profitable.

Proof of Proposition 3.1(iii). Suppose Firm 2 offers price $p_2^* = w_M q_2$ and instead is able to match Firm 1's quality via $q_2^* = \frac{w_M}{k_2^{'} c_2}$. For this to be feasible, it must be true that $c_2 \leq \frac{w_M h_1^{'}}{w_T k_2^{'}} c_1$. The firm thus has the opportunity to attract both segments at that quality level, and thus

$$P_2 = \left[\frac{w_M^2}{k_2^{'} c_2} - \frac{w_M^2}{[k_2^{'}]^2 c_2} \right] [a_2 T_0 + b_2 M_0] \qquad \text{(A3.5).}$$

If (A3.5) is greater than (A3.3) and (A3.2), then the firm will serve both segments. Otherwise, the firm will serve only one segment, which reduces to the choice in (A3.4).

A.3.3 Proof of Proposition 3.2. The proof of Proposition 3.1 applies with $p_1^* = w_M q_1$ and $p_2 = \frac{w_M}{k_1^{'} c_1}$ for $k_1^{'} \in (1,2]$.

A.3.4 Proof of Proposition 3.3.

For (i), if $p_1^* = w_T q_1$, then Lemma 1 indicates that $q_1^* = \frac{w_T}{h_1^{'} c_1}$ for $h_1^{'} \in (1,2]$. For Firm 1 to attract the innovative segment, it must match Firm 2's quality so that $\frac{w_T}{h_1^{'} c_1} \geq Max\left[\frac{w_T}{h_2^{'} c_2}, \frac{w_M}{k_2^{'} c_2} \right]$. If $.5c_2 \leq c_1 \leq c_2$, then for $q_1^* = \frac{w_T}{2c_1}$, $Max\left[\frac{w_T}{h_2^{'} c_2}, \frac{w_M}{k_2^{'} c_2} \right]$ is at most

$\frac{w_T}{2h_2^{'}c_1}$, where $h_2^{'} \in (1,2]$. Thus, Firm 1's efficient quality of $q_1^* = \frac{w_T}{2c_1}$ will always be able to match Firm 2's quality for the innovative segment, and

$$P_1 = \left[\frac{w_T^2}{4c_1}\right] a_1 T_0 . \tag{A3.6}$$

For (ii), given Lemma 1, Firm 1 will be able to attract the mainstream segment regardless of Firm 2's price as long as $p_1^* = w_M q_1$. Firm 1's profits are (A3.3) with the appropriate change in subscripts. The profit from the innovative segment is larger if

$$\frac{w_T^2}{w_M^2} > \frac{b_1 M_0}{a_1 T_0} . \tag{A3.7}$$

A.3.5 Proof of Proposition 3.4.

For (i), if $p_1^* = w_T q_1$, then Lemma 1 indicates that $q_1^* = \frac{w_T}{h_1^{'}c_1}$ for $h_1^{'} \in (1,2]$. For Firm 1 to attract the innovative segment, it must match Firm 2's quality so that $\frac{w_T}{h_1^{'}c_1} \geq Max\left[\frac{w_T}{h_2^{'}c_2}, \frac{w_M}{k_2^{'}c_2}\right]$. If $c_2 < c_1 < 2c_2$, then for $q_1^* = \frac{w_T}{h_1^{'}c_1}$, $Max\left[\frac{w_T}{h_2^{'}c_2}, \frac{w_M}{k_2^{'}c_2}\right]$ is less than $\frac{w_T}{c_1}$. Thus, Firm 1 will always be able to set $h_1^{'} \in (1,2]$ to match the late entrant's quality level and will earn (A2) in profits with the appropriate change in subscripts.
For (ii), given Lemma 1, Firm 1 will be able to attract the mainstream segment regardless of Firm 2's price as long as $p_1^* = w_M q_1$. Firm 1's profits are (A3) with the appropriate change in subscripts. The profit from the innovative segment is larger if (A4) is true (with the appropriate change in subscripts).

A.3.6 Proof of Proposition 3.5.

We compare profits from Proposition 3.3(i) to Propositions 3.1 and 3.2. The firm's profit from the mainstream segment is the same regardless of order entry, so we focus on profit from the innovator segment. When Firm 1 is the first mover, its efficient quality is optimal for the entire range where $.5c_2 \leq c_1 \leq c_2$. Thus, to prove that Firm 1 increases profit as a first mover, we only need to find a range where Firm 1's efficient quality is not optimal.

Proposition 3.3.1(ii) and (iii) show the existence of such a range when Firm 2 sets price $p_2^* = w_T q_2$ and $q_2^* = \frac{w_T}{h_2^{'}c_2}$. For the range $\frac{h_1^{'}}{2} c_j < c_i < c_j$, where $k_1^{'} \in (1,2]$, Firm 1 must match Firm 2's quality rather than selecting the efficient quality, and thus profits are lower. Thus Firm 1 is more profitable when it is the first mover if it has a cost advantage where $.5c_2 \leq c_1 < c_2$.

Endnotes

[1] The original 1957 model uses $[m - I(t)]/m$ as opposed to $m - I(t)$. We can add $1/m$ by adjusting β_i accordingly.

[2] Comparative static analysis for the general functions f_i and g_i is done using the Implicit Function Theorem (e.g. Currier 2000). Since all cross-derivatives equal 0, given parameter μ for new venture I, $\frac{\partial a_i}{\partial \mu} = \frac{\partial^2 P_i / \partial a_i \partial \mu}{-\partial^2 P_i / \partial a_i^2}$ and $\frac{\partial w_i}{\partial \mu} = \frac{\partial^2 P_i / \partial w_i \partial \mu}{-\partial^2 P_i / \partial w_i^2}$. The results hold when f_i and g_i are increasing concave functions for both new ventures.

[3] For both new firms, an increase in m, the industry ceiling, means an increase in the number of sales that can be realized, and thus causes an increase in their expenditures on unrealized sales, end-of-period sales, and profit.

[4] We note that some parameter values such as excessively high effectiveness in attracting unrealized sales or unit profit margin will result in nearly infinite expenditure spending in the short term. In such cases, the algorithm cannot find a feasible solution.

[5] A different time horizon may yield, for instance, different end-of-horizon sales for both new firms, but the direction of the sensitivity relationships appears robust to the length of the time horizon.

[6] The Gartner analysis group defines smartphones as "[a] large-screen, data-centric, handheld device designed to offer complete phone functions whilst simultaneously functioning as a personal digital assistant (PDA)" (Best, 2006).

[7] A full exposition of the advantages and disadvantages of standardization versus differentiation appears in Besen and Farrell (1994).

[8] Thus, for instance, a firm may previously have attracted 8% of prospective customers, but survey instruments show that an additional 2% would purchase if both firms added technology, resulting in a 10% attraction.

[9] The number would need be adjusted according to customer purchasing habits for the industry. For instance, customers who just purchased from the firm may be unlikely to purchase from the firm again.

[10] Pure as opposed to mixed-strategy Nash equilibrium in which one or both firms randomly select their action because neither action is optimal, given the action of the other firm.

[11] I.e., $P_i(1,0) > P_i(0,0)$ and firm i possesses the dominant strategy of adding technology, or $P_j(0,1) > P_j(0,0)$ and firm j possesses the dominant strategy of adding technology.

[12] To increase profits according to Equation (2.17), the firm should add technology if its rival does so because $P_i(1,1) > P_i(0,1)$. However, the firm should maintain the status quo if its rival does so because $P_i(0,0) > P_i(1,0)$. Hence, the firm faces no dominant strategy and must know its rival's technology choice in order to optimize its decision.

[13] If the firm and rival do not have a dominant strategy, their strategies either match, yielding two Nash equilibria, or clash, yielding no Nash equilibrium. We note that this result contradicts that of Belleflamme (1998), who found that an equilibrium partition always exists.

[14] In mathematical terms, we investigate if $\rho_i(\varphi_i, \varphi_j)$ and $\rho_j(\varphi_i, \varphi_j)$ can be ordered such that $\rho_i(1,1) > \rho_i(0,1)$ and $\rho_j(0,1) > \rho_j(1,1)$ for the condition in Proposition 2.5(i), $\rho_i(1,0) > \rho_i(0,0)$ and $\rho_j(0,0) > \rho_j(1,0)$ for 2.5(ii), $\rho_j(1,1) > \rho_j(1,0)$ and $\rho_i(1,0) > \rho_i(1,1)$ for 2.5(iii), and $\rho_j(0,1) > \rho_j(0,0)$ and $\rho_i(0,0) > \rho_i(0,1)$ for 2.5(iv).

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