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Abstract

In technology markets, new features targeted at existing high-end customers are often introduced with each new generation of product. For example, Microsoft's Xbox 360 gaming system was not only able to play games in High Definition, it also came with a more sophisticated controller. We call this accelerating the technology treadmill. On the other hand, sometimes the new feature emphasizes an alternate performance dimension to attract new customers: Nintendo's new Wii video game system introduced an easier-to-use interface targeted at new customers. We refer to this as stepping off the technology treadmill. We model a situation where each of two firms chooses whether or not to introduce one type of new feature or the other or neither, and each firm simultaneously sets product performance along the traditional dimension. We find that the firms either both accelerate the technology treadmill, both step off the technology treadmill, or they introduce opposite feature types. Interestingly, in the latter case the firm introducing the new feature targeted at new customers prefers that it be only marginally attractive.

1 Introduction

In November 2006, Nintendo introduced a new interface for its console in its bid for market share in the video game industry. Instead of adding more buttons to the traditional controller as they and their competitors had done over the past few generations, they introduced a motion sensitive controller for their console, named the Wii (pronounced 'we'). Nintendo's controller requires the gamer to move her body to control the on-screen characters instead of pushing a series of buttons as on the more traditional controller. When Nintendo announced this innovation many core gamers, traditionally young males, ridiculed Nintendo for introducing a gimmicky controller. On the other hand, these same core gamers applauded Microsoft's Xbox 360 and Sony's PS3 for their introduction of more complicated controllers and games in High Definition which offers more accurate control, more realistic graphics, and better audio. However, Nintendo hoped to attract previous non-gamers to their console; people who are intimidated by the increasing number of buttons on the controllers.

In developing their strategy, perhaps Nintendo looked back to when Apple introduced the thumbwheel on its iPod, as an alternative to an MP3 device controlled by multiple buttons. Similar to the Wii controller, the thumbwheel was an easier-to-use feature for uninitiated users. Kodak's

EasyShare is another example of a new feature intended to make the product easier to use, rather than push the technology. We use the term "new feature" to generically suggest a change in design such that the new feature offers a significant change with regard to the original feature. The new feature can either be targeted at new customers (as in the case of the Wii controller) or current customers (as in the case of the Microsoft's Xbox 360 controller).

The conditions under which a firm finds it optimal to introduce a new feature targeted at new customers is an interesting question because this strategy lies in stark contrast to what we frequently observe in technology products. Generally, in each new generation, firms push the state-of-the-art technology to a higher level and introduce features targeted at current high-end customer needs, in order to extract premium prices (Porter 1985). For example, in the video game industry not only were the graphics and CPU speed enhanced in every new generation previous to the Wii, but also, the controllers became more sophisticated and therefore harder to use by uninitiated users. Thus firms in high-tech industries are typically trying to accelerate the technology treadmill – they not only increase the technology of the products in each generation, they also incorporate new features which are typically targeted at the high-end consumer. Nintendo is adopting a different strategy; it aims to gain ground on its competitors not by continuing this escalation with the Wii, but by stepping off this treadmill and introducing a new feature specifically targeted at the non-gamers.

Nintendo's vice-president of sales and marketing described his firm's strategy by citing two popular managerial books, the Blue Ocean Strategy (Kim and Mauborgne 2005) and The Innovator's Dilemma (Christensen 1997): "Looking at the current state of the videogame market, we believe there's a strong argument for expanding the audience beyond the current core players, attracting players by rethinking what a videogame means, and delivering our entertaining in a more convenient and affordable fashion" (Casamassina 2005). In their design process they did not focus as much on the core gamers, whom Sony and Microsoft were targeting, but rather on current non-gamers. They wanted to compete in a "blue ocean" rather than a "red one" (Kim and Mauborgne 2005), and thereby "disrupt" the nature of competition (Christensen 1997). Our model intends to gain insight into the conditions under which this is an optimal strategy.

So suppose you are a manager at a technology firm, competing in the current period in an existing market along the traditional performance dimensions, and are designing a new generation product for a future period. Should you stay on the treadmill and continue to play the escalation game with your competitor by augmenting the technology with high-end features, or should you (figuratively) step off the treadmill and change the nature of competition by introducing a feature focusing on new customers? As inferred by the comments of the Nintendo VP, and by the two books referenced above, a key factor to consider is how the market's existing customers and non-customers will view the potential competitive products.

In our stylized model, we view the product's level of performance along the traditional dimensions (i.e., its traditional attributes) as being described by one measure. We call this measure the product's "technology index," and assume all customers prefer a higher technology index (i.e., we assume this performance dimension is vertically differentiated, Mussa and Rosen 1978). In the video game industry, we can for example think of the CPU speed, combined with the graphics and sound quality to determine the technology index of a video game console. Furthermore, we assume customers differ in their preference intensities, such that while all customers prefer a higher technology index, for any given index some customers are willing to pay more than others. Those customers with the highest willingness to pay for any given technology index will be referred to as the high-end customers. Alternatively, those with a lower willingness to pay are called lower-end customers.

As a result of varying customer preference intensities, each firm (our model assumes two competitors) has to decide what level of technology index it should offer and at what price, in order to maximize its profit. In the current period, we assume the new feature is not yet available, so firms compete strictly with regard to technology index and price. Similar to Moorthy (1988) we find the market is segmented into a "high-tech" firm and a "lower-tech" firm where we set the technology index for the high-tech firm equal to one, representing state-of-the-art technology.

In the second period, each firm not only sets the technology index but also decides whether to offer one of two new features. A new feature effectively represents a second attribute of the product. We assume the new feature is either one that is appreciated by the high end of the market and not appreciated by the low end (i.e., customer preferences for the second attribute are positively correlated with customer preferences for the first attribute), or vice-versa (i.e., negatively correlated). For brevity we simply refer to these as the positively and negatively-correlated new features. For example, if the new feature is of the negatively-correlated type (as is the case with Nintendo's new interface for the Wii), the highest-end customers have a negative utility for the new feature (recall the disdain of the avid gamers for the Wii controller). In this case the technology index and the new feature have a conflicting effect on customer's perception: the high-end customers place a high value on the technology index and a low (even negative) value on the new feature, while the lower-end customers place a lower importance on the technology index and a higher importance on the new feature. This type of new feature models the environment described by Christensen (1992): he found disruptive innovation in a market where the strength of a customers' preference for the primary attribute (in our case, the technology index) is negatively correlated with strength of preference for the second attribute (the new feature). Alternatively, the new feature can be one where customer perception is positively correlated with the technology index, in which case the lowest-end customers (i.e., non-buyers) perceive the new product to be even less attractive than if the new feature had not been added (refer back to our example of more video game controller buttons).

More specifically, in our model a new feature is defined by two parameters, which together describe the collective customer reaction to its incorporation into the new product, and in turn determine the market outcome. This allows us to map out nine possible cases: each firm can choose to introduce a negatively correlated new feature, introduce a positively correlated new feature, or introduce no new feature (we will refer to this case as sticking with the original feature, e.g., keeping the same video game controller). We determine which of these is the Nash equilibrium outcome (i.e., which firm(s) if any will introduce which feature), given the customer reactions to each new feature.

Our results suggest that both firms always introduce one of the new features. Either both firms accelerate the treadmill (as exemplified by the gaming industry where firms continually added buttons on the controller), or one firm jumps off the treadmill and one accelerates it (as observed with the Wii and Xbox 360), or both firms jump off it (Sony imitated some of the Wii's motion sensitive functionality just in time for the launch of their PS3). Furthermore, if the lower-tech firm introduces the negatively correlated new feature we surprisingly find that it prefers that the new feature be only marginally attractive to the consumers.

In section 2 we relate our work to the current literature. In section 3 we formally develop the analytical model. We compare the profits under different parameter values for each of the nine possible cases in section 4. We summarize and discuss our results in section 5.

2 Relation to the Literature

Our work is related to a long line of research in the field of vertically differentiated products, where all customers show a "more is better" appreciation but differ in their preference intensities. Mussa and Rosen (1978) initiated work in this field, and examined a monopoly situation. Gabszewicz and Thisse (1979) extended their work to a situation with multiple firms, which competed on one attribute (usually referred to as the quality), and price. This shows similarities with the first period in our model where the firms only compete on the technology index, i.e. the key dimension or quality of the product, and price.

Shaked and Sutton (1982) more formally examine a three stage model in which firms 1) decide to enter, 2) set qualities, and 3) set prices to maximize profits. They concluded that under general conditions the maximum number of firms to enter is two, offering different qualities. More than two firms led to a price war and zero profits for all firms involved. Thus, they called this phenomenon the natural duopoly. We similarly focus on two firms each offering one product.

While our technology index reflects the case of vertical differentiation, customer "tastes" came into play in our model in the sense that some would prefer the negatively-correlated feature and others the positively-correlated feature. Another way of modeling customer taste is through horizontal differentiation; again, there is a large stream of literature originating with Hotelling (1929), who found that two firms would converge to the middle of the market to maximize their market shares. Waterson (1989) provides a survey of literature in this area. A paper that combines horizontal and vertical differentiation in the model is for example Bohlmann, Golder and Mitra (2002).

As in our first period, Moorthy (1988) also identifies the optimal level of one attribute for two firms in competition. He refers to the single attribute as quality, while we use the term technology index as we specifically focus on technology markets. Similar to us he assumed customer willingness to pay is linear in customer type, but he used quadratic unit costs to naturally bind the quality from growing to infinity while we assume cost is linear in the technology index but assume it is constrained at some level we call the "state-of-the-art" technology. We are thus able to find explicit closed form analytical solutions (Moorthy's are implicit) for the second firm's technology index (falling somewhere between zero and 100% of the state-of-the-art). Also, where Moorthy was interested in determining the firms' optimal profits and for example Ofek and Srinivasan (2002) were interested in the dollar impact of a feature modification, we are more interested in the impact of the new feature on the firms' choices.

When a new dimension is added to a product as in our model, firms compete on multiple attributes. A recent paper by Krishnan and Zhu (2006) examines what they refer to as the overlapped product-design approach, in which a low-end product, i.e. lower-tech product, is differentiated on additional vertical dimensions. They conclude that this is a good alternative to merely degrading a high-end product. In our paper we take a closer look at the case where either the high-end or the low-end product comes equipped with an additional vertical dimension. They examine the case where fixed development costs far outweigh the unit-variable costs, which they then assume to be equal to zero, while we assume unit cost is linear in the technology index in order to model technology markets such as the gaming industry (for example, each $399 Xbox 360 costs Microsoft $524 to assemble, Hesseldahl 2005).

Our paper is closely related to Vandenbosch and Weinberg (1995), abbreviated V&W, who determined how two firms would position products vertically differentiated on two attributes. We similarly determine each firm's optimal technology index (the first attribute), and whether or not the firms introduce the new feature (the second attribute). However, in V&W's setup, customer preferences are by definition positively correlated, while in our paper they can also be negatively correlated. V&W's model extends upon Hauser's (1988) approach which also looked at two attributes. Hauser confined them to the positive quadrant of a circle, practically collapsing them into one attribute, while V&W explicitly model uniformly distributed preferences for both attributes. Our model uses a similar approach to Hauser as we add up the part worths for the two attributes into one reservation price. This allows us to explicitly model unit costs, which V&W did not do. Similar to V&W's model, customers in our model at most purchase one product from one of the firms (Lancaster 1979). However, we allow for a non-purchase, which coincides with Moorthy's (1988) definition of purchasing a third product with zero quality and costs, while in V&W the whole market is by definition covered. Finally, as V&W did not apply unit costs, they conclude that the firms behave in a MaxMin solution (maximum differentiation on one dimension and minimum differentiation on the other). Due to our differing approach firms do not behave in this manner but instead the high-tech and lower-tech firms may either both pursue the same type of new feature or opposite types, depending on the market reaction.

More recent papers which show similarities with our work are by Schmidt and Porteus (2000) and Druehl and Schmidt (2006) as they also examine multiple attributes and allow for customer preferences to be negatively or positively correlated. However, they take costs to be exogenous, and also take product attributes to be exogenous, while we endogenize aspects of both of these factors. Also, our model extends their works as either firm has the choice of introducing the new feature, whereas the product characteristics in their papers are given (i.e., they do not consider the product features and attribute levels to be decision variables).

3 The model

We consider two firms and two periods. In the first (current) period the firms only compete on price and a single vertical dimension, which we call the technology index (the new features are not available to the firms in the first period). In the second period (this can be thought of as the future period), each firm has the option to introduce one of two new features for its product (referred to as the positively and negatively-correlated new features, as discussed later), as well as to again set the technology index for its new product. The description of the model as consisting of two periods is a convenience that allows us in the first period to distinguish one of the firms as the high-tech firm and the other as the lower-tech firm, to compare and contrast our first-period formulation with that of Moorthy (1988), and to set the stage for our key results that are derived in the second period (given our assumptions, firms act myopically rather than strategically in the first period).

3.1 Period 1 Market outcome (no new features)

The setup in the first period is similar to that of Moorthy (1988) except that in our model we exogenously normalize the technology index of the high-tech product to 100%, while in his model the quality (which is synonymous with our technology index) of either product can take on any positive value. We assume unit cost is linear in the technologiy index (he assumes quadratic costs), which enables us to find explicit closed form solutions for the optimal technology index of the lower-tech product, while Moorthy's solutions are implicit. We numerically studied the case where unit costs were quadratic and found qualitatively similar results to those presented herein but given that these were not closed form solutions, we chose to use the linear cost formulation.

Following Moorthy (1988), we assume that customers show different intensities in their preferences, i.e. some customers are more willing to pay for a given technology index (i.e., have a higher part worth for this attribute level) than others, and assume that customers are distributed uniformly with regard to customer type w (where a customer's type is defined by her willingness to pay). We normalize the scale for customer type to run from zero to one. Given any technology index, this results in a linear part-worth curve for that index (a part-worth curve is a plot of willingness to pay versus customer type as shown in Figure 1).

See Table 1 for a summary of notation. We denote the two firms as firm H and firm L because as we will see, the first period equilibrium results in one firm (firm H) choosing a high technology index t_H, and the other firm (firm L) choosing a lower technology index t_L. We set the value of the high-tech index equal to one (i.e., $t_H = 1$), associating the index of one with state-of-the-art technology. In other words, the high-tech firm's part-worth curve for the technology index in Figure 1 intercepts the y axis at one, while the lower-tech firm's technology index part-worth curve intercepts the y axis at less than one.

Parameters/Variables	Explanation
w	Customer type $\sim Unif(0,1)$
H	Denotes the high-tech firm (as well as the high-tech product)
L	Denotes the lower-tech firm (as well as the lower-tech product)
j	Denotes the firm and the product: $j \in \{L, H\}$ (subscript)
h	Denotes the type of feature from firm H: $h \in \{N, O, P\}$ (superscript)
l	Denotes the type of feature from firm L: $l \in \{N, O, P\}$ (superscript)
t_j^{hl}	The *technology* index of product j (we set $t_H^{hl} = 1$), case hl
$u_j^{hl}(w)$	*Utility* for customer of type w for product j, case hl
$s_j^{hl}(w)$	Utility *surplus* for customer of type w for product j, case hl
p_j^{hl}	The *price* for product j, case hl
M_j^{hl}	The *market* coverage of firm j, case hl
Π_j^{hl}	The *profit* of firm j, case hl
c	The unit *cost* parameter, $0 \leq c \leq 1$
r	Customers' *reaction* to the new feature, $0 \leq r < 1$
i	*Indifferent* customer with respect to the new feature, $0 \leq i \leq 1$
w_L^{hl}	Indifferent customer between product L and no purchase, case hl
w_H^{hl}	Indifferent customer between products H and L, case hl

Table 1 - Parameters and decision variables

A customer is assumed to buy the product that maximizes her utility surplus $s_j(w),\ j \in \{L, H\}$, which is the customer's utility $u_j(w) = wt_j$ minus the product's selling price p_j, or to buy neither if her surpluses for both products are negative. We assume firms are unable to price discriminate (there is only one price for each product). The customer who is indifferent between purchasing the lower-tech product and not purchasing any product is denoted by $w_L = p_L/t_L$, while the customer who is indifferent between purchasing the high-tech product and the lower-tech product is denoted by $w_H = (p_H - p_L)/(1 - t_L)$. These can be determined from $w_L t_L - p_L = 0$ and $w_H t_L - p_L = w_H - p_H$. The high-tech product sells to customers in $[w_H, 1)$ and the lower-tech product sells to customers in $[w_L, w_H)$. We denote the fraction of the total market covered by a firm as its market *coverage*, $M_H = 1 - w_H$ and $M_L = w_H - w_L$ such that $0 \leq M_j \leq 1$. A firm's profit Π_j is its market coverage multiplied by the margin, where margin is price p_j minus the unit cost $c_j = c\ t_j$where c is an exogenously given cost parameter. This leads to the following profit functions:

$$\begin{aligned}
\Pi_L &= \left(\frac{p_H - p_L}{1 - t_L} - \frac{p_L}{t_L}\right)(p_L - ct_L)\,. \\
\Pi_H &= \left(1 - \frac{p_H - p_L}{1 - t_L}\right)(p_H - c)\,.
\end{aligned}$$

Simultaneously maximizing these profit functions yields $t_L = 4/7$ (the profit functions are strictly concave). Thus firm L sets its technology index at slightly more than half the technology index of firm H. This leads to prices and profits shown in (1). As one would expect, prices inrease as the cost parameter c increases, while the market coverages and profits decrease (and drop to zero for $c \geq 1$).

Comparing our linear unit cost structure with Moorthy's (1988) quadratic structure, we find firm H has a big advantage in terms of market coverage (twice firm L's) and profit (seven times firm L's) while while in Moorthy's (1998) quadratic structure firm H has only a marginal advantage[1]. If we were to use quadratic unit costs (while continuing to cap the technology index at 1), firm L comes out ahead as c increases (the squared costs "hurt" the high-tech firm H), but closed form analytical solutions are no longer attainable.

[1]Going through his model we are not able to duplicate his answer which shows an advantage for the lower-tech firm (in solving his model we find $\Pi_l \approx 0.0122\frac{b^3}{\alpha}$ and $\Pi_h \approx 0.0164\frac{b^3}{\alpha}$).

$$
\begin{array}{lll}
p_L = \frac{1}{14}(1+7c) & M_L = \frac{7}{24}(1-c) & \Pi_L = \frac{1}{48}(1-c)^2 \\
p_H = \frac{1}{4}(1+3c) & M_H = \frac{7}{12}(1-c) = 2M_L & \Pi_H = \frac{7}{48}(1-c)^2 = 7\Pi_L
\end{array} \tag{1}
$$

3.2 Period 2 Market outcome (new features are an option)

In the second period the firm has an opportunity to introduce one of two new features (or neither new feature), and to re-set its technology index and price. We assume that customer preferences (i.e., part worths) for a new feature are either perfectly negatively correlated or perfectly positively correlated with customer part worths for the technology index - for brevity we simply refer to the two new features as the "negatively-correlated" and "positively-correlated" types. If the new feature is negatively correlated as illustrated in Figure 1, then the higher the customer's part worth for the technology index, the lower that customer's part worth for the new feature, and the part-worth curve of the new feature is linear and opposite sloping to that of the technology index. Our model is restrictive in assuming either perfect negative or positive correlation, but the gaming industry example lends support to the assumption and our modeling parsimony allows us to separate out the impact of such correlation.

The possibility for each firm to introduce a negatively-correlated new feature (denoted by N), or a positively-correlated new feature (denoted by P), or to introduce neither and stick with the original feature (denoted by the letter O), leads to nine cases to consider in the second period. The cases will be denoted by superscripts indicating the high-tech firm H's decision followed by the lower-tech firm L's decision. For example, the case where the high-tech firm introduces the negatively-correlated feature and the lower-tech firm incorporates the positively-correlated one is denoted by a superscript of ^{NP}. Thus t_L^{hl} denotes the technology index of firm L when the high-tech and lower-tech firms' new-feature choices are $h \in \{N, O, P\}$ and $l \in \{N, O, P\}$, respectively. Note that $t_H^{hl} = 1$ under all outcomes (the technology index of firm H is always re-indexed to one, to represent the state-of-the-art in the new generation of products). The two possible new features are assumed to be exogenous in that they are available to either firm without investment, and there is no opportunity for a firm to improve on a feature as compared to the other firm. While this is clearly simplistic, our intent is to examine when firms have incentives to pursue new features and whether these new features will be "alike" or "unalike" - in real markets these incentives may of course be either strengthened or weakened by internal factors, but our model offers a starting point for gaining insight.

We assume there is some customer who is indifferent between the new and original features - we denote the indifferent customer by i. For example, if the new feature is negatively correlated, then customers who are "higher-end" than i dislike the new feature and those who are "lower-end" than i like it. Alternatively, if the new feature is positively correlated, then both part-worth curves have a positive slope and customers who are higher-end than i like the new feature. We focus on $0 \leq i \leq 1$, because at $i < 0$ no customers appreciate the new feature, and it would never be introduced, while at $i > 1$ all customers have a positive value for the new feature, and it would always be introduced given our assumption of zero additional costs.

A product's reservation price curve is a "full-worth" curve or simply the sum of the two part-worth curves (i.e., those for the new feature and the technology index). If the firm chooses not to introduce either new feature (and stick with the original feature, so to speak), then the reservation price curve is simply represented by the part-worth curve for the technology index (any part-worth attributable to the original feature is assumed to be contained in the part-worth curve for the technology index).

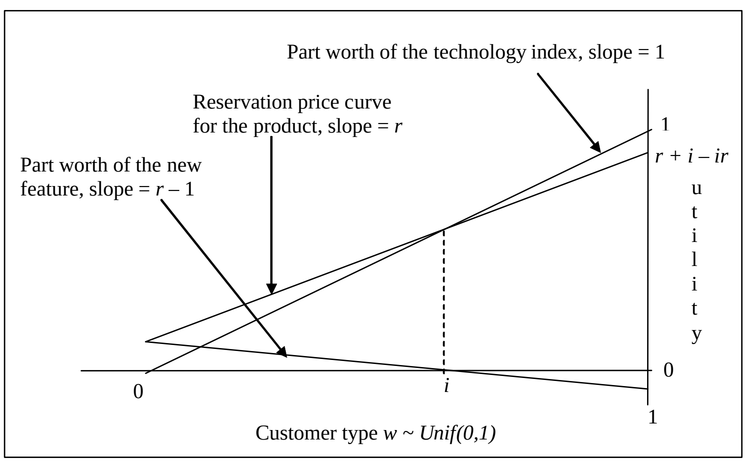

Figure 1 - Example of part worths for the technology index and a negatively-correlated new feature for the high-tech product.

If the high-tech firm incorporates the negatively-correlated new feature, we denote the slope of its reservation price curve by the exogenous parameter r (continue to refer to Figure 1 - the slope of the negatively-correlated new feature's part-worth curve is thus $r - 1$). Given the negative-correlation, this means $r < 1$. We assume that if the lower-tech product incorporates the negatively-correlated feature then its reservation price curve is similarly "flattened;" that is, the slope of its reservation price curve is $r\ t_L^{hN}$. Thus for any given r the customer's absolute reaction to the new feature on the high-tech product is greater than on the lower-tech product. We choose this over an additive measure (where the impact would be the same absolute amount) because we presume that customers are in general more discriminating when evaluating a high-priced high-tech product. If the high-tech product contains the positively-correlated new feature, we assume the slope of its reservation price curve is $\frac{1}{r}$, while if the lower-tech product incorporates it then its slope is similarly steepened to $\frac{1}{r}\ t_L^{hP}$.

Again, a customer is assumed to buy the product that maximizes her utility surplus $s_j^{hl}(w) = u_j^{hl}(w) - p_j^{hl}$, or to buy neither if the surpluses for both products are negative. The various equations for customer utility given the type of feature are shown in Table 2. For example: in case ^{NP} : $u_L^{NP}(w) = \frac{(w-i)}{r} t_L^{NP} + it_L^{NP}$ and $u_H^{NP}(w) = (w-i)\, r + i$.

Feature	Utilities ($u_j^{hl}(w)$)
Negatively-correlated	$(w-i)\, rt_j^{hl} + it_j^{hl}$
Original	wt_j^{hl}
Positively-correlated	$\frac{(w-i)}{r} t_j^{hl} + it_j^{hl}$

Table 2 - the utility surplus given the type of feature.

We continue to assume that unit cost is linear in the technology index $c_j^{hl} = c\ t_j^{hl}$, regardless of whether the product contains the new feature - for example, this means our model might be most applicable to a situation where the new feature replaces a more traditional feature and therefore feature costs are comparable (e.g., the new Nintendo Wii controller replaced the traditional sophisticated multi-button controller). A firm's profit is $\Pi_j^{hl} = M_j^{hl}(p_j^{hl} - c\ t_j^{hl})$, where the market coverages M_j^{hl} are determined by the two types of indifferent customers as shown in Table 3. For example: $M_L^{NO} = w_H^{NO} - w_L^{NO}$. Note that case ^{OO} (where neither firm introduces a new feature) is effectively covered by the first period results given in (1).

Case	w_L^{hl}	w_H^{hl}
OO	$\frac{p_L^{OO}}{t_L^{OO}}$	$\frac{p_H^{OO}-p_L^{OO}}{1-t_L^{OO}}$
NN	$\frac{p_L^{NN}-it_L^{NN}(1-r)}{rt_L^{NN}}$	$\frac{p_H^{NN}-p_L^{NN}-i\left(1-t_L^{NN}\right)(1-r)}{r\left(1-t_L^{NN}\right)}$
PP	$\frac{rp_L^{PP}+it_L^{PP}(1-r)}{t_L^{PP}}$	$\frac{r\left(p_H^{PP}-p_L^{PP}\right)+i\left(1-t_L^{PP}\right)(1-r)}{\left(1-t_L^{PP}\right)}$
NO	$\frac{p_L^{NO}}{t_L^{NO}}$	$\frac{p_H^{NO}-p_L^{NO}-i(1-r)}{r-t_L^{NO}}$
PO	$\frac{p_L^{PO}}{t_L^{PO}}$	$\frac{r\left(p_H^{PO}-p_L^{PO}\right)+i(1-r)}{1-rt_L^{PO}}$
ON	$\frac{p_L^{ON}-it_L^{ON}(1-r)}{rt_L^{ON}}$	$\frac{p_H^{ON}-p_L^{ON}+it_L^{ON}(1-r)}{1-rt_L^{ON}}$
OP	$\frac{rp_L^{OP}+it_L^{OP}(1-r)}{t_L^{OP}}$	$\frac{r\left(p_H^{OP}-p_L^{OP}\right)-it_L^{OP}(1-r)}{r-t_L^{OP}}$
PN	$\frac{p_L^{PN}-it_L^{PN}(1-r)}{rt_L^{PN}}$	$\frac{r\left(p_H^{PN}-p_L^{PN}\right)-ir\left(1-t_L^{PN}\right)}{1-r^2t_L^{PN}}+i$
NP	$\frac{rp_L^{NP}+it_L^{NP}(1-r)}{t_L^{NP}}$	$\frac{r\left(p_H^{NP}-p_L^{NP}\right)-ir\left(1-t_L^{NP}\right)}{r^2-t_L^{NP}}+i$

Table 3 - the indifferent customers for the nine cases.

3.2.1 Cases ^{NO} and ^{PO}: Only firm H introduces a new feature

The dotted upward-sloping lines in Figure 2 illustrate a pair of part-worth curves for firms H and L, portraying the part-worth for the technology index (these curves intercept the y-axis at $t_H^{hl}=1$ and at t_L^{hl}, respectively). The solid upward-sloping lines illustrate a pair of reservation price curves for firms H and L when each introduces the negatively-correlated new feature.

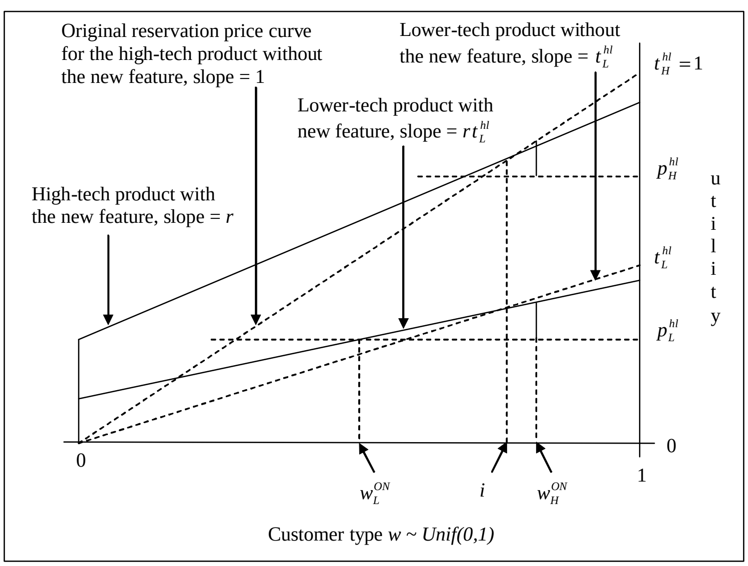

Figure 2 - Reservation price curves for the original feature (dotted lines) and the negatively-correlated new feature (solid lines)

For case ^{NO} the pertinent reservation price curves in Figure 2 are the upper solid line for the high-tech firm and the lower dotted line for the lower-tech firm. We follow the same steps as described in section 3.1 to determine the optimal technology index of the lower-tech product. Given that the first-order condition results in a third-order polynomial, we find three possible solutions for t_L^{NO}, only one of which falls between $0 < t_L^{NO} < 1$. The expression for t_L^{NO} can be found in Appendix A and Figure 3 shows how this variable behaves as a function of r. When the high-tech firm introduces the negatively-correlated feature and that feature elicits a strong customer reaction (i.e., r is small), the high-tech firm is in effect catering more toward the lower-tech firm's lower-end market, and the lower-tech firm responds by further decreasing its technology index to in a sense move even further down-market (note in Figure 3 that t_L^{NO} is decreasing in r).

For case ^{PO} the solution (as given in Appendix A) is the same as for case ^{NO}, except that r is replaced with $\frac{1}{r}$. (Note that the solution for case ^{NO} is given in terms of the high-tech product's slope r, such that for case ^{PO} it follows logically that the solution would be given in terms of the high-tech product's slope $\frac{1}{r}$). The behavior of t_L^{PO} is also shown in Figure 3 - when the high-tech firm introduces the positively-correlated feature and that feature elicits a strong customer reaction (i.e., $1/r$ is big), the high-tech firm is in effect catering even more strongly toward its high-end market and the lower-tech firm feels a bit less pressure and responds by increasing its technology index.

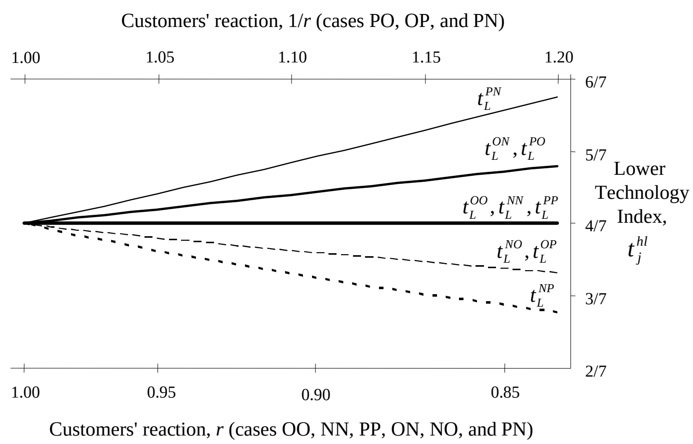

Figure 3 - the lower technology index as a function of (graph for $i/c = 1$).

Figure 3 is shown for $i = c$. When $i \neq c$ the lower curves for cases ^{ON} and ^{PO} are no longer superimposed on each other (and neither are the curves for cases ^{NO} and ^{OP}), but the results are otherwise qualitatively similar.

3.2.2 Cases ^{ON} and ^{OP}: Only firm L introduces a new feature

For case ^{ON} the pertinent reservation price curves in Figure 2 are the lower solid line for the lower-tech firm and the upper dotted line for the high-tech firm. We use the same process as above to determine the optimal technology index of the lower-tech product; the closed form solution can be found in Appendix A along with the solution for case ^{OP} which is found by replacing r with $\frac{1}{r}$. The behavior of the lower-tech firm's technology index in these cases is again shown in Figure 3. Introduction of the negatively-correlated feature by (only) the lower-tech firm helps create further differentiation and thus the lower-tech firm feels emboldened to increase its technology index (and introduction of the positively correlated new feature effectively creates more competition such that the lower-tech firm pulls back on the technology index).

3.2.3 Cases ^{NN},^{PP} ,^{PN} , and ^{NP}: Both firms introduce a new feature

We first look at cases ^{NN} and ^{PP} where the new features are "alike" and then look at cases ^{PN} and ^{NP} where they are "unalike."

Cases ^{NN} and ^{PP}: the new features are alike The pertinent reservation price curves in Figure 2 for case ^{NN} are the two upward-sloping solid lines. Because both firms' reservation price curves are affected "equally" by the introduction of the new feature, we find (as in the case of no new feature) that $t_L^{NN} = \frac{4}{7}$ independent of r. For case ^{PP} we similarly find $t_L^{PP} = \frac{4}{7}$. The prices, market coverages and profits are comparable to (1) and given by:

$$\begin{array}{lll} p_L^{NN} = \frac{1}{14}(y+7c) & M_L^{NN} = \frac{7}{24}(y-c) & \Pi_L^{NN} = \frac{1}{48}(y-c)^2 \\ p_H^{NN} = \frac{1}{4}(y+3c) & M_H^{NN} = \frac{7}{12}(y-c) = 2M_L^{NN} & \Pi_H^{NN} = \frac{7}{48}(y-c)^2 = 7\Pi_L^{NN} \end{array} \quad (2)$$

$$\text{where } y = r + i - ir$$

The solution for case ^{PP} can be obtained by replacing r with $\frac{1}{r}$. It can be easily seen that for $r = 1$ (the new feature has no impact), (2) matches (1) as y is then equal to 1.

Cases ^{PN} and ^{NP}: the new features are unalike Given our assumption that i is the same for both new feature types, any customer who likes one feature dislikes the other. The solution for t_L^{PN} as given in Appendix A is illsutrated in Figure 3 (as is the solution for case ^{NP} which involves replacing r with $\frac{1}{r}$). The more intuitively appealing case is case ^{PN} where firm L introduces a negatively correlated new feature (yielding a product with relative slope $= r$), while firm H introduces the positively correlated new feature (resulting in a product with slope $= \frac{1}{r}$), such that both firms effectively target their respective ends of the market. This results in the lower-tech firm significantly increasing its technology index as the customers' reaction becomes more prominent (i.e., as r decreases or $\frac{1}{r}$increases).

4 The Nash equilibrium outcome in period 2

Before we compare across the nine possible outcomes in section 4.2 to determine the Nash equilibrium, we state four propositions followed by a corollary (all proofs can be found in Appendix B).

4.1 Propositions

Proposition 1 *For any* $0 \leq i \leq 1$ *and* $0 < r < 1$ *all the profit functions* $\Pi_j^{hl}, h, l \in \{N, O, P\}, j \in \{L, H\}$ *are decreasing in* c.

Proposition 1 means that independent of how customers react to the new feature, a firm's profit decreases as the unit cost of the technology index increases.

Proposition 2 *If* $i = c$*, then for any given* $0 < r < 1$ *we find* $\Pi_j^{PO} = \Pi_j^{PN} = \Pi_j^{PP} > \Pi_j^{OO} = \Pi_j^{ON} = \Pi_j^{OP} > \Pi_j^{NO} = \Pi_j^{NN} = \Pi_j^{NP},\ j \in \{L, H\}$.

The implication of Proposition 2 is that if the indifferent customer's willingness to pay is equal to the unit cost of the technology index, then the Nash equilibrium outcome will be for firm H to introduce the positively-correlated new feature while firm L is indifferent between its three options. That is, the equilibrium is any of ^{PO}, ^{PN}, or ^{PP}.

Proposition 3 *For any given* $0 < r < 1$ *and* $0 \leq c \leq 1$*:*

a) The profit for the firm which introduces a negatively (positively) correlated new feature in isolation is increasing (decreasing) in i*.*

b) The profit for the firm which sticks with the original feature, while the competitor introduces a negatively (positively) correlated new feature is decreasing (increasing) in i*.*

c) If both firms introduce negatively (positively) correlated new features, then the profits for the firms increase (decrease) in i.

d) If firm H introduces a positively-correlated new feature and firm L introduces a negatively-correlated new feature, then the profit for firm H is decreasing in i, while the profit for firm L is increasing in i.

Proposition 3 can be summarized by stating that the firms benefit if more customers like *their* new feature while they suffer when more customers like the competitor's new feature. Also, Propositions 2 and 3 together indicate that a firm won't introduce the negatively-correlated new feature if $i < c$.

Next we state two lemmas that identify the values of i where the profits in cases ^{OO} and ^{NN}, and cases ^{NN} and ^{PP} are equal.

Lemma 1 *At* $i = \frac{c+\sqrt{r}}{1+\sqrt{r}} : \Pi_j^{OO} = \Pi_j^{NN},\ j \in \{L, H\}$.

Lemma 2 *At* $i = \frac{1+c}{2} : \Pi_j^{NN} = \Pi_j^{PP},\ j \in \{L, H\}$.

These Lemmas follow directly from the closed form solutions for the profit functions. As $\Pi_j^{NN},\ j \in \{L, H\}$ is increasing in i for both firms (Proposition 3), Lemma 1 indicates that for $i < \frac{c+\sqrt{r}}{1+\sqrt{r}} : \Pi_j^{OO} > \Pi_j^{NN}$, while for $i > \frac{c+\sqrt{r}}{1+\sqrt{r}} : \Pi_j^{OO} < \Pi_j^{NN}$. Likewise, Lemma 2 indicates that for $i < \frac{1+c}{2} : \Pi_j^{NN} < \Pi_j^{PP}$, while for $i > \frac{1+c}{2} : \Pi_j^{NN} > \Pi_j^{PP}$ as $\Pi_j^{PP},\ j \in \{L, H\}$ is decreasing in i.

To establish Proposition 4 we make four natural assumptions. Specifically, we assume:

$$\begin{aligned}
\frac{d}{di}\Pi_L^{NP} &< \frac{d}{di}\Pi_L^{NO}, & (3)\\
\frac{d}{di}\Pi_H^{NP} &> \frac{d}{di}\Pi_H^{OP}, & (4)\\
\frac{d}{di}\Pi_L^{PN} &> \frac{d}{di}\Pi_L^{PO}, & (5)\\
\frac{d}{di}\Pi_H^{PN} &< \frac{d}{di}\Pi_H^{PP}. & (6)
\end{aligned}$$

For example, inequality (6) seems to be a reasonable assumption because in case ^{PN} firm H's profits decrease in i both because it introduces a positively correlated new feature and firm L introduces a negatively correlated new feature, while in case ^{PP} both firms introduce a positively correlated new feature. This will later be seen in Figure 5 where firm H's profits decline in i much faster in case ^{PN} than in case ^{PP}. The other assumptions can be argued in much the same way and we find all these assumptions to hold in numerical analysis run over an extensive set of values for $0 \leq i \leq 1$, $0 \leq c \leq 1$ and r relatively close to 1 (e.g. $\frac{5}{6} < r < 1$).

Proposition 4 *There exists an* $x \in \left\{c, \frac{1+c}{2}\right\}$, *such that the Nash equilibria are:*

$$\begin{cases} \textit{Case}^{\ PP} & \textit{if} \quad 0 \leq i \leq c \\ \textit{Case}^{\ PN} & \textit{if} \quad c < i \leq x \\ \textit{Case}^{\ NN} & \textit{if} \quad x < i \leq 1 \end{cases}$$

Proposition 4 leads to the following corollary, with results depicted graphically in Figure 4 to be discussed in more detail later.

Corollary 1 *Both firms will always introduce a new feature and will either target the same end of the market (i.e., will either both introduce the positively-correlated new feature, or will both introduce the negatively-correlated new feature), or each firm will target its own end of the market (i.e. firm L will introduce the negatively correlated new feature, while firm H introduces the positively correlated new feature).*

This is not an immediately obvious result as customers at one of the market will always have a negative utility for the negatively or positively correlated new feature. Regardless, both firms find it optimal to always introduce a new feature of one type or the other.

4.2 Nash equilibria as a function of the parameters

Figure 4 graphically depicts the analytical result of Proposition 4 for a fixed $r = 0.95$ ($\frac{1}{r} \approx 1.05$). There are only three Nash equilibria out of the nine cases separated by the lines $i = c$ and $i = x$. For $0 \leq i \leq c$ the Nash equilibrium is case ^{PP}, where both firms introduce the positively-correlated new feature. The set of customers who appreciate this feature starts at the high-end of the market and extends a significant distance down market. For higher values of i, i.e., within the region $c < i \leq x$, fewer of the lower-end customers appreciate the positively-correlated new feature and instead these lower-end customers appreciate the negatively-correlated one. Thus the lower-tech firm switches its decision and opts to go for the negatively-correlated feature - the high-tech firm sticks with the positively-correlated feature as it still caters to the high-end customers (yielding case ^{PN}). Finally, if the set of customers who appreciate the negatively-correlated new feature is large enough (i.e., when $x < i \leq 1$), then firm H also introduces the negatively-correlated new feature, such that case ^{NN} is the Nash equilibrium.

However, it is useful to further delineate case ^{NN} into two regions as for $x < i \leq \frac{c+\sqrt{r}}{1+\sqrt{r}}$ the firms are locked in a prisoner's dilemma (PD, Tucker 1950). That is, each firm could generate higher profits by not introducing any new feature (case ^{OO}) than by both introducing negatively-correlated ones (case ^{NN}). The reason for this phenomenon is that even though the market share is increasing somewhat (new customers are attracted to the market), the profit maximizing price they firms can charge is lower in case ^{NN} than in case ^{OO} as for a large percentage of high-end customers the utility is decreased by the negatively-correlated new feature. Only when $\frac{c+\sqrt{r}}{1+\sqrt{r}} < i \leq 1$ do so many customers appreciate the negatively-correlated new feature that both firms can profit from introducing it (i.e. the firms' profit in case ^{NN} is higher than in case ^{OO} for $i > \frac{c+\sqrt{r}}{1+\sqrt{r}}$ as per Lemma 1 and Proposition 3). The prisoner's dilemma is also clearly shown in section 4.3, where we show the actual profits.

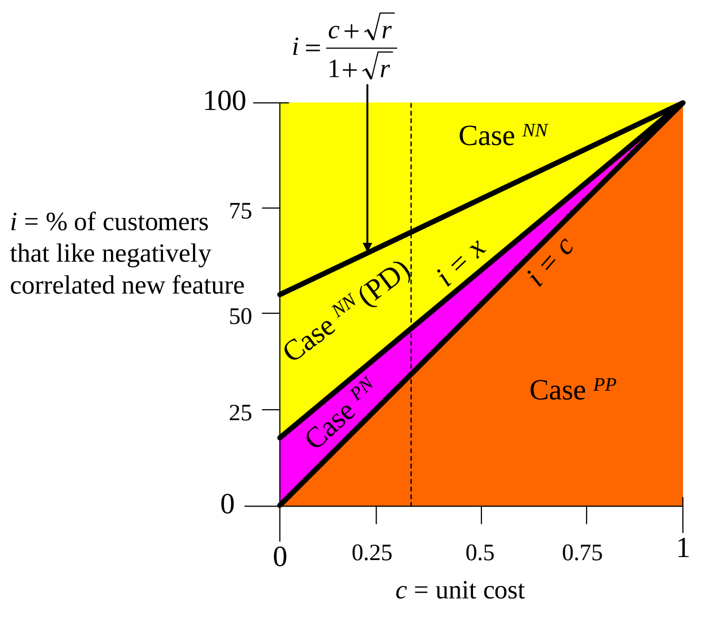

Figure 4 - Market outcomes showing which firm introduces what kind of new feature ($r = 0.95$).

Figure 4 is relatively robust with respect to r. For example, using an r of 0.80 lowers the intersection of $i = x$ with the i-axis ($c = 0$) from 0.16 to 0.14, while the intersection of $i = \frac{c+\sqrt{r}}{1+\sqrt{r}}$

with the i-axis is then at 0.47 instead of at 0.49. The profits are also very similar: for example, at $i = 0.50$ and $c = 0.33$ the profits at the Nash equilibrium case ^{NN} for $r = 0.95$ are: $\Pi_H^{NN} = 0.0639, \Pi_L^{NN} = 0.0091$, while at $r = 0.80$ they are: $\Pi_H^{NN} = 0.0592, \Pi_L^{NN} = 0.0085$. We therefore focus more on the impact of i and c on the firms' decisions in the discussion section , rather than on r.

4.3 The profits as a function of the parameters

To further illustrate the results, we plot the firms' profits for $r = 0.95$ and $c = 0.33$ in Figure 5 (these are the profits along the vertical dotted line in Figure 4).

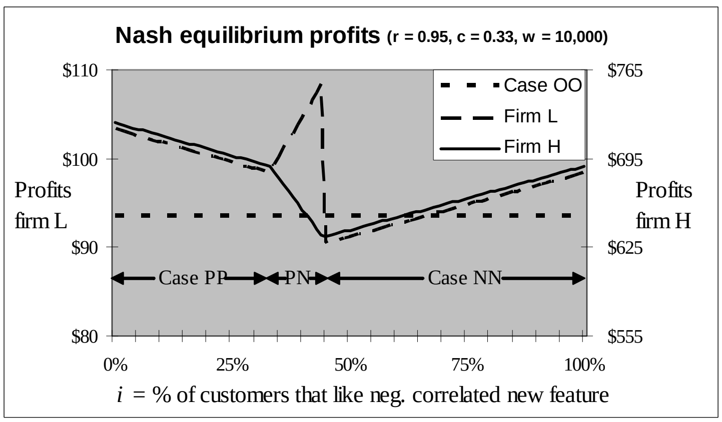

Figure 5 - Profits as a function of i (both firms' profits for case ^{OO} are represented by the horizontal dotted line).

Starting at the left of Figure 5 where $i = 0$, both introduce the positively correlated new feature (case ^{PP}) for $0 \leq i \leq c = 0.33$. For $0.33 = c < i \leq x = 0.45$ firm L's profits increase in i while firm H's profits decrease in i, since firm L now introduces a negatively correlated new feature. Also, Figure 5 shows that our assumption (6) that firm H's profit decrease at a higher rate in case ^{PN} than in case ^{PP} holds.

For $x < i \leq 1$ both firms introduce the negatively correlated new feature and for $x \leq i < \frac{c+\sqrt{r}}{1+\sqrt{r}} = 0.66$ their profits are lower than if neither firm would introduce a new feature, while for $\frac{c+\sqrt{r}}{1+\sqrt{r}} < i \leq 1$ their profits are higher. Thus, for $x \leq i < \frac{c+\sqrt{r}}{1+\sqrt{r}}$ the firms are locked in a prisoner's dilemma. Also note that firm L's profits are maximized for $i = x - \varepsilon$.

The above discussion indicates that in a high tech environment where the firms can choose what kind of new feature to introduce, both firms will always offer a new feature under the assumptions of our model, but that this behavior does not always lead to higher profits.

Corollary 2 *Both firms will always introduce a new feature but will not always realize higher profits compared to neither firm introducing a new feature.*

5 Discussion and Summary

With each new generation of product, a high-tech firm must decide whether to augment the pace of technological development by adding a new high-end feature to its product; or whether to figuratively step off the technological treadmill by introducing a feature targeted not toward the high-end but toward lower-end customers; or to do neither (simply stick with existing features, while possibly upgrading the existing core technology). Our motivating example has been the gaming industry, where firms repeatedly followed the augmentation strategy by introducing more and more sophisticated controllers, until finally in late 2006 Nintendo introduced the "simplistic" Wii controller.

Why did Nintendo choose to step off the treadmill when it did so? Why did firms continually follow the augmentation strategy prior to 2006? Why was it Nintendo that chose to step off the treadmill, while simultaneously we find that Microsoft continued to pursue the augmentation strategy? Our model pursues insights into these conditions in a game-theoretic setting involving two competing firms. In our model the firms' decision are dependent on how customers perceive the new features – in a sense, we find that there are times when the market is "ripe" for stepping off the treadmill, and when it is "still ripening."

In our model each of two firms chooses between the three scenarios described above (augmenting the pace, or stepping off the treadmill, or sticking with the existing feature). We assume there are two possible new features: with the "positively correlated" version there is a positive relationship between a customer's part-worth utility for the new feature and her part-worth utility for the product's "technology index," and with the "negatively-correlated" new feature there is a negative correlation.

We find that if the variable costs are high then both firms generally benefit most from introducing the positively correlated new feature targeted at current high-end customers' needs. (Refer back to Figure 4 – at high costs all but the very uppermost portion is cover by case ^{PP}.) This is because high costs lead to high prices, and to a relatively small market that consists of only the very highest-end customers. The fact that lower-end customers don't appreciate the new feature is immaterial (these customers are non-buyers anyway). We find that one firm offers a lower-tech product than the other (and consequently sells to a market that is slightly less high-end) – even this lower-tech firm finds that it is to its benefit to "accelerate the treadmill" by incorporating the positively-correlated new feature. This may help explain why early in the life of a new technology when costs are still high, we observe that the treadmill is often repeatedly accelerated.

However, as the cost of the new feature is reduced (through learning, for example – see Schmidt and Wood 1999), there is a greater range over which both firms find it advantageous to introduce the new feature. If there are enough customers who appreciate a negatively correlated new feature, then one or both firms will introduce it: if the number (i in Figure 4) is "big enough but not too big," then only the firm which offers the lower-tech product introduces the negatively-correlated new feature as it targets the lower-tech firm's end of the market (the high-tech firm introduces the positively-correlated new feature for its end of the market). If the number of customers preferring the negatively-correlated new feature is high enough then both firms introduce it - but they may have been better off had neither done so (they find themselves in a prisoner's dilemma). Only if a very large percentage of customers like the negatively correlated new feature can both firms profit from introducing it.

Over the three decades in which the video game industry has existed, high-end customers became used to very sophisticated gaming consoles, and these high-end customers drove the market to introduce controllers with more buttons. But such a new controller "raises the bar" in terms of the level of expertise required to play the game, such that the segment of customers who appreciate this postively-correlated new feature may diminish to include only the very highest-end. Said another way, the fraction of customers that might respond to a negatively-correlated new feature (a more user-friendly controller) is now higher. Our model suggests that if this latter fraction is "high enough," then the lower-tech firm introduces the negatively-correlated new feature that attracts new customers, while the high-tech firm introduces the positively-correlated one. The gaming industry supports this results, given Nintendo's introduction of the Wii as compared to Sony and Microsoft who chose to offer state-of-the-art consoles with more complicated controllers. Likewise, in the cell phone industry current customers are increasingly interested in new high-tech features, and the high-tech iPhone delivers. Some lower end competitors like Jitterbug instead offer simplicity for those users not interested in complicated phones with lots of functions.

In Christensen's (1992) context of disruptive innovation, an interesting result of ours is that the high-tech firm does not benefit from introducing the negatively-correlated new feature unless enough customers like it. Thus while Christensen (1997) suggests that a high-tech incumbent is acting sub-optimally by not adopting the disruptive innovation, it may actually be best off by allowing a lower-tech entrant to encroach on the low-end of the market. Of course, this assumes that our second period reservation price curves do in fact reflect customer preferences over the lifetime of the new product – our model does not take into account dynamic improvements in the reservation prices of the new feature over time, an assumption upon which the story of disruptive innovation is predicated. What our model does suggest, however, is that in cases where these dramatic gains for the negatively-correlated new feature do not materialize over time, the incumbent can in fact be best off by not introducing this new feature. This possibility should not be ignored.

Other limitations to our model are that we do not consider additional variable costs or fixed (e.g. R&D) costs for the new feature, as we assumed that the new feature replaces the existing one. Thus a possible extension could be to look at additional variable costs, or potentially fixed costs. Another logical extension would be to look at the case involving more than two firms.

In our model the firms are unable to influence the reaction of existing and potential customers to the new feature. A third possible extension could address this by allowing the firms to allocate campaign funds to influence the customers' reactions. Our current results hint that the firm offering the lower-tech product (when compared with the high-tech firm's state-of-the-art product) could increase its profits with an ad campaign that succeeds in promoting the negatively-correlated new feature, but only up to a point - if too many people are convinced of its merits, then the high-tech firm also offers it and destroys the lower-tech firm's profits (refer back to Figure 5). On the other hand, the high-tech firm faces a dilemma. It can either continue to advertise the superiority of its own positively-correlated new feature (and thereby work to diminish the number of customers who "switch" to preferring the negatively-correlated feature), or it can itself change camps and focus its advertising on the negatively-correlated feature in order to maximize the number of new customers who favor it (it then becomes optimal for both firms to adopt the negatively-correlated new feature, and profits for both firms increase as more customers favor it). If it decides to change camps the high-tech firm faces the risk of putting the firms in a prisoner's dilemma where both would be better off not introducing the negatively-correlated new feature (the ad campains promoting the new feature must be quite successful in order to bring the firms back out of this dilemma).

Our current model is static in that firms make decisions simultaneously, so we cannot technically describe the above sequential scenario. However, it is interesting to compare these strategic maneuvering implications with the actual marketing campaigns implemented by Nintendo and Sony in the video game industry. When Nintendo decided to step off of the technology treadmill and introduce the new controller, Sony and Microsoft scrutinized Nintendo's efforts and emphasized Wii's inability to play games in High Definition. However, they possibly underestimated the number of customers who would ultimately appreciate the new controller given Nintendo's promotions during the development phase (by the time the Wii's introduction date approached, a higher than anticipated percentage of customers was interested in the new controller). As a result, Sony's strategy changed from one of ridiculing Nintendo's efforts to one of imitating them and incorporating some of Wii's motion-sensitive functionality into Sony's own controller. Microsoft's Xbox 360 had already been on the market for a while when the Wii was introduced, so Microsoft could not respond likewise and it continues to downplay the Wii's capabilities.

Given this situation, our model suggests Sony's decision to "switch camps" could lead to the prisoner's dilemma where both firms introduce the negatively-correlated new feature but would be better off not doing so. The industry seems to agree as one analyst on a popular video games site (IGN Staff 2006) pointed out: "Nintendo has been an innovator from the very beginning, and the best compliment is imitation. Of course, it's a little different when that imitation could put you out of business, right?" On the other hand, the combined efforts of Sony and Nintendo may be to yield a customer reaction that is so positive that the outcome will be one where both firms profit (even if this is the case, Nintendo would still likely have been better off had Sony not imitated them). The moral of this story is that Nintendo may now stand to lose millions as compared to what they might have made had not so many customers shown appreciation for their new controller. Nintendo would have preferred to independently step off the technology treadmill while the competitor accelerated it, to further differentiate itself.

Appendix A

In this appendix we show the closed form solutions for t_L^{NO}, t_L^{ON}, and t_L^{PN}. The solutions for

t_L^{PO}, t_L^{OP}, and t_L^{NP} can be found by replacing r by $\frac{1}{r}$.

$$\begin{aligned} t_L^{NO} &= \frac{r}{2}\left(\frac{r\,(11-10c-i)+(i-c)-\sqrt{3D}}{r\,(7-5c-2i)+2\,(i-c)}\right), \\ \text{where } D &= r^2\left(3-34i+28c+11i^2-20c^2+12ic\right)+r\left(34i-34c-22i^2+12c^2+10ic\right)+11\,(i-c)^2\,. \end{aligned}$$

Note that this solution only holds for $D \geq 0$. When $D < 0$ we do not consider this case as a possible Nash equilibrium.

$$\begin{aligned} t_L^{ON} &= \frac{1}{2r}\left(\frac{r\,(11-c-10i)+10\,(i-c)-\sqrt{3E}}{r\,(7-2c-5i)+5\,(i-c)}\right), \\ \text{where } E &= r^2\left(3+28i-34c-20i^2+11c^2+12ic\right)+4r\left(7c-7i+10i^2+3c^2-13ic\right)-20\,(i-c)^2\,. \end{aligned}$$

Note that this solution only holds for $E \geq 0$. When $E < 0$ we do not consider this case as a possible Nash equilibrium.

$$\begin{aligned} t_L^{PN} &= \frac{1}{2r^2}\left(\frac{11r\,(1-i)+\left(10+r^2\right)(i-c)-\sqrt{3F}}{7r\,(1-i)+\left(5+2r^2\right)(i-c)}\right) \\ \text{where } F &= 2r\,(1-i)\,(i-c)\left(17r^2-14\right)+(i-c)^2\left(11r^4+12r^2-20\right)+3r^2\,(1-i)^2\,. \end{aligned}$$

Note that this solution only holds for $F \geq 0$. When $F < 0$ we do not consider this case as a possible Nash equilibrium.

Appendix B

In this appendix we prove the propositions stated in section 4.1 of the text. Before we do so we (re)state the expressions for the nine profit functions. Those for cases ^{OO}, ^{NN}, and ^{PP} are the closed form solutions, while those for the other cases are the expressions using the technology index and the prices. We define the margin each firm makes per product sold by $\rho_j^{hl} = \left(p_j^{hl} - ct_j^{hl}\right)$, $j \in$

$\{H, L\}; h, l \in \{N, O, P\}$. All the margins ρ_j^{hl} have to be positive to constitute a valid solution.

Case	Profit firm L	Profit firm H
OO	$\frac{1}{48}(1-c)^2$	$\frac{7}{48}(1-c)^2$
NN	$\frac{1}{48r}(r+i-ir-c)^2$	$\frac{7}{48r}(r+i-ir-c)^2$
PP	$\frac{r}{48}\left(\frac{1}{r}+i-\frac{i}{r}-c\right)^2$	$\frac{7r}{48}\left(\frac{1}{r}+i-\frac{i}{r}-c\right)^2$
NO	$\left(\frac{p_H^{NO}-p_L^{NO}-i(1-r)}{r-t_L^{NO}}-\frac{p_L^{NO}}{t_L^{NO}}\right)\rho_L^{NO}$	$\left(1-\frac{p_H^{NO}-p_L^{NO}-i(1-r)}{r-t_L^{NO}}\right)\rho_H^{NO}$
PO	$\left(\frac{p_H^{PO}-p_L^{PO}-i\left(1-\frac{1}{r}\right)}{\frac{1}{r}-t_L^{PO}}-\frac{p_L^{PO}}{t_L^{PO}}\right)\rho_L^{PO}$	$\left(1-\frac{p_H^{PO}-p_L^{PO}-i\left(1-\frac{1}{r}\right)}{\frac{1}{r}-t_L^{PO}}\right)\rho_H^{PO}$
ON	$\left(\frac{p_H^{ON}-p_L^{ON}+it_L^{ON}(1-r)}{1-rt_L^{ON}}-\frac{p_L^{ON}-it_L^{ON}(1-r)}{rt_L^{ON}}\right)\rho_L^{ON}$	$\left(1-\frac{p_H^{ON}-p_L^{ON}+it_L^{ON}(1-r)}{1-rt_L^{ON}}\right)\rho_H^{ON}$
OP	$\left(\frac{p_H^{OP}-p_L^{OP}+it_L^{OP}\left(1-\frac{1}{r}\right)}{1-\frac{t_L^{OP}}{r}}-\frac{p_L^{OP}-it_L^{OP}\left(1-\frac{1}{r}\right)}{\frac{t_L^{OP}}{r}}\right)\rho_L^{OP}$	$\left(1-\frac{p_H^{OP}-p_L^{OP}+it_L^{OP}\left(1-\frac{1}{r}\right)}{1-\frac{t_L^{OP}}{r}}\right)\rho_H^{OP}$
PN	$\left(\frac{r\left(p_H^{PN}-p_L^{PN}\right)-ir\left(1-t_L^{PN}\right)}{1-r^2t_L^{PN}}+i-\frac{p_L^{PN}-it_L^{PN}(1-r)}{rt_L^{PN}}\right)\rho_L^{PN}$	$\left(1-\frac{r\left(p_H^{PN}-p_L^{PN}\right)-ir\left(1-t_L^{PN}\right)}{1-r^2t_L^{PN}}-i\right)\rho_H^{PN}$
NP	$\left(\frac{\frac{1}{r}\left(p_H^{NP}-p_L^{NP}\right)-\frac{i}{r}\left(1-t_L^{NP}\right)}{1-\frac{t_L^{NP}}{r^2}}+i-\frac{p_L^{NP}-it_L^{NP}\left(1-\frac{1}{r}\right)}{\frac{t_L^{NP}}{r}}\right)\rho_L^{NP}$	$\left(1-\frac{\frac{1}{r}\left(p_H^{NP}-p_L^{NP}\right)-\frac{i}{r}\left(1-t_L^{NP}\right)}{1-\frac{t_L^{NP}}{r^2}}-i\right)\rho_H^{NP}$

Proposition 1:

Proof. Taking the derivative of the profit function with respect to c:

$$\frac{d}{dc}\Pi_j^{hl} = -t_j^{hl} M_j^{hl} \leq 0,\ \ j \in \{L, H\}; h, l \in \{N, O, P\}.$$

Thus all of these are equal to minus the technology index multiplied by the market coverage. As the market coverage has to be greater than zero to constitute a valid solution, we conclude that all the profit functions are decreasing in c independent of r and i. ■

Proposition 2:

Proof. At $i = c$, the expressions for t_L^{hl} simplify to the point where we can express the profits in closed form. The technology indices and the resulting profits in the nine cases are then as follows:

t_L^{hl}	$i = c$ $\times \frac{4}{7}$	Firm L neg.	orig.	pos.
	negative	1	r	r^2
Firm H	original	$\frac{1}{r}$	1	r
	positive	$\frac{1}{r^2}$	$\frac{1}{r}$	1

Thus, the technology index of the lower-tech firm adjusts such that a comparable level of differentiation is maintained compared to period one. These lead to the following profit functions at $i = c$:

Π_j^{hl}	$i = c$ $\times \frac{m}{48}(1-c)^2$	Firm L neg.	orig.	pos.
	negative	r	r	r
Firm H	original	1	1	1
	positive	$\frac{1}{r}$	$\frac{1}{r}$	$\frac{1}{r}$

$$, m = \begin{cases} 1 \text{ if } j = L \\ 7 \text{ if } j = H \end{cases}$$

■

Proposition 3:

Proof. For this proof we first derive the following:

$t_L^{NO} = \frac{r}{2}\left[\frac{r(11-10c-i)+(i-c)-\sqrt{3D}}{r(7-5c-2i)+2(i-c)}\right] = r\left[\frac{r(11-10c-i)+(i-c)-\sqrt{3D}}{r(11-10c-i)+(i-c)+3(r+i-ir-c)}\right] \overset{i \gtrless c}{<} r$ and

$t_L^{OP} = \frac{r}{2}\left[\frac{\frac{1}{r}(11-c-10i)+10(i-c)-\sqrt{3E}}{\frac{1}{r}(7-2c-5i)+5(i-c)}\right] = r\left[\frac{(11-c-10i)+10r(i-c)-r\sqrt{3E}}{(11-c-10i)+10r(i-c)+3(1-c)}\right] < r.$

a) We take the derivative of the profit functions for cases ^{ON},^{OP},^{NO}, and ^{PO} with respect to i for the firm which introduces the new feature:

$$\begin{aligned}
\frac{d}{di}\Pi_L^{ON} &= \frac{1}{r}\left(\frac{1-r}{1-rt_L^{ON}}\right)\left(p_L^{ON} - ct_L^{ON}\right) > 0. \\
\frac{d}{di}\Pi_L^{OP} &= -r\left(\frac{1-r}{r-t_L^{OP}}\right)\left(p_L^{OP} - ct_L^{OP}\right) < 0. \\
\frac{d}{di}\Pi_H^{NO} &= \left(\frac{1-r}{r-t_L^{NO}}\right)\left(p_H^{NO} - c\right) \overset{i \gtrless c}{>} 0. \\
\frac{d}{di}\Pi_H^{PO} &= -\left(\frac{1-r}{1-rt_L^{PO}}\right)\left(p_H^{PO} - c\right) < 0.
\end{aligned}$$

The fact that $\frac{d}{di}\Pi_H^{NO}$ is only greater than 0 for $i \geq c$ is not an extra restriction as firms are only possibly interested in negatively-correlated new features for $i \geq c$.

b) We take the derivatives of the profit functions in cases ^{ON},^{OP},^{NO}, and ^{PO} with respect to i for the firm which does not introduce the new feature:

$$\begin{aligned}
\frac{d}{di}\Pi_H^{ON} &= -t_L^{ON}\left(\frac{1-r}{1-rt_L^{ON}}\right)\left(p_H^{ON}-c\right)<0. \\
\frac{d}{di}\Pi_H^{OP} &= t_L^{OP}\left(\frac{1-r}{r-t_L^{OP}}\right)\left(p_H^{OP}-c\right)>0. \\
\frac{d}{di}\Pi_L^{NO} &= -\left(\frac{1-r}{r-t_L^{NO}}\right)\left(p_L^{NO}-ct_L^{NO}\right)\overset{i\geq c}{<}0. \\
\frac{d}{di}\Pi_L^{PO} &= \left(\frac{1-r}{1-rt_L^{PO}}\right)\left(p_L^{PO}-ct_L^{PO}\right)>0.
\end{aligned}$$

c) The profit functions for cases ^{NN} and ^{PP} can be rewritten as $\Pi_j^{NN}=\frac{m}{48r}\left(r-c+i\left(1-r\right)\right)^2$ and $\Pi_j^{PP}=\frac{mr}{48}\left(\frac{1}{r}-c+i\left(1-\frac{1}{r}\right)\right)^2,\ j\in\{L,H\}$. Thus, the profits in case ^{NN} (^{PP}) are increasing (decreasing) in i.

d) We take the derivatives of the profit functions for case ^{PN} with respect to i:

$$\begin{aligned}
\frac{d}{di}\Pi_L^{PN} &= \frac{1}{r}\left(\frac{1-r^2}{1-r^2t_L^{PN}}\right)\left(p_L^{PN}-ct_L^{PN}\right)>0. \\
\frac{d}{di}\Pi_H^{PN} &= -\left(1+rt_L^{PN}\right)\left(\frac{1-r}{1-r^2t_L^{PN}}\right)\left(p_H^{PN}-c\right)<0.
\end{aligned}$$

■

Proposition 4:

Proof. The proof is in three parts. We first establish the Nash equilibrium for $0\leq i<c$, followed by the two Nash equilibria for $c\leq i\leq 1$. In the third part we proof x's existence.

(i) At $i=c$ the Nash equilibrium is either case ^{PO},^{PN} or ^{PP}. As $\frac{d}{di}\Pi_L^{PP}<0,\ j\in\{L,H\}$ and $\frac{d}{di}\Pi_L^{PN},\frac{d}{di}\Pi_L^{PO}>0,\ j\in\{L,H\}$ (Proposition 3), the Nash equilibrium for $i=c-\varepsilon$ is case ^{PP}. Neither firm would like to deviate from this strategy for any $0\leq i<c$ as for firm H it holds that $\frac{d}{di}\Pi_H^{NP}>\frac{d}{di}\Pi_H^{OP}>0$ (by 4), while for firm L it holds that $\frac{d}{di}\Pi_L^{PO},\frac{d}{di}\Pi_L^{PN}>0$ (Proposition 3). Thus, for $0\leq i\leq c$ the Nash equilibrium is case ^{PP}.

(ii) As at $i=c:\Pi_H^{PP}=\Pi_H^{PN}>\Pi_H^{OO}>\Pi_H^{NN}$ (Proposition 2), and $\frac{d}{di}\Pi_L^{PN}>\frac{d}{di}\Pi_L^{PO}>0$ (by 5), while $\frac{d}{di}\Pi_L^{PP} < 0$ (Proposition 3), the Nash equilibrium for $i = c + \varepsilon$ is case ^{PN}. Firm L does not deviate from this strategy for any $c \leq i \leq 1$ as $\frac{d}{di}\Pi_L^{PN} > \frac{d}{di}\Pi_L^{PO} > 0$ (again by 5) and $\frac{d}{di}\Pi_L^{PP} < 0$ (Proposition 3). Firm H will only deviate if either $\Pi_H^{NN} \geq \Pi_H^{PN}$ or $\Pi_H^{ON} \geq \Pi_H^{PN}$.

(iii) As $\frac{d}{di}\Pi_H^{NN} > 0$ and $\frac{d}{di}\Pi_H^{ON} < 0$ (Proposition 3) and $\frac{d}{di}\Pi_H^{PN} < \frac{d}{di}\Pi_H^{PP} < 0$ (by 6) and as at $i = \frac{1+c}{2} : \Pi_H^{NN} = \Pi_H^{PP}$ (Lemma 2), it must hold that $\Pi_H^{NN} = \Pi_H^{PN}$ at some $i = x \in \left\{c, \frac{1+c}{2}\right\}$. As $\frac{d}{di}\Pi_H^{NN} > 0$ and $\frac{d}{di}\Pi_H^{ON} < 0$ (Proposition 3) and $\frac{d}{di}\Pi_H^{PN} < \frac{d}{di}\Pi_H^{PP} < 0$ (by 6), the Nash equilibrium for $x < i \leq 1$ is case ^{NN}. Neither firm would like to deviate from this strategy for any $x < i \leq 1$ as for firm H it holds that $\frac{d}{di}\Pi_H^{ON} < 0$ (Proposition 3) and $\frac{d}{di}\Pi_H^{PN} < \frac{d}{di}\Pi_H^{PP} < 0$ (by 6), while for firm L it holds that $\frac{d}{di}\Pi_L^{NP} < \frac{d}{di}\Pi_L^{NO} < 0$ (by 3). ■

References

Bohlmann, J.D., Peter N. Golder, Debanjan Mitra. 2002. Deconstructing the Pioneer's Advantage: Examining Vintage Effects and Consumer Valuations of Quality and Variety. *Management Science*, **48**(9) 1175-1195

Casamassina, Matt. 2005. Reggie Talks DS and Revolution. The full article is accessible at http://cube.ign.com/articles/665/665952p1.html as of 10-20-06

Christensen, Clayton M. (1992). *The innovator's challenge: Understanding the influence of market environment on processes of technology development in the rigid disk drive industry.* Unpublished doctoral dissertation, Harvard Business School.

Christensen, C. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* Harvard Business School Press, Boston, MA

Christensen, C., M. Raynor. 2003. *The Innovator's Solution.* Harvard Business School Press, Boston, MA

Druehl, C. T., G. M. Schmidt. 2006. A Strategy for Opening a New Market and Encroaching on the Lower End of the Existing Market. Working paper, University of Utah

Hauser, J. R. 1988. Competitive price and positioning strategies. *Marketing Science*, **7**(1) 76-91

Hesseldahl, Arik. 2005. Microsoft's Red-Ink Game. The full article is accessible at http://www.businessweek.com/technology/content/nov2005/tc20051122_410710.htm?chan=search as of 10-20-06.

Hotelling, H. 1929. Stability in competition, *Economic Journal*, **39** 41–57

IGN Staff. 2006. E3 2006: Seeing The Difference. The full article is accessible at http://wii.ign.com/articles/705/705870p1.html as of 10-20-06

Kim, Chan W., Renée Mauborgne. 2005. *Blue Ocean Strategy: How to Create Uncontested Market Space and Make Competition Irrelevant*. Harvard Business School Press, Boston, MA

Krishnan, V., Zhu, W. 2006. Designing a Family of Development-Intensive Products. *Management Science*, **52**(6) 813-825

Lancaster, K. 1979. *Variety, equity, and efficiency.* Columbia University Press, NY

Moorthy, K. S. 1988. Product and price competition in a duopoly. *Marketing Science*, **7**(2) 141-168

Mussa, M., S. Rosen. 1978. Monopoly and product quality. *Journal of Economic Theory*, **18** 301-317

Ofek, Elie, V. Srinivasan. 2002. How much does the market value an improvement in a product attribute? *Marketing Science*, **21**(4) 398-411

Porter, M. 1985. *Competitive advantage.* The Free Press, New York, NY

Schmidt, G.M., S. Wood. 1999. The growth of Intel, and the learning curve. Stanford University Graduate

School of Business, Case Study S-OIT-27.

Schmidt, G. M., E. L. Porteus. 2000. The impact of an integrated marketing and manufacturing innovation. *Manufacturing & Service Operations Management*, **2**(4) 317-336

Shaked, A., J. Sutton. 1982. Relaxing price competition through product differentiation. *The Review of Economic Studies*, **49** 3-13

Tucker, A.W. 1950. *A two-person dilemma*, Mimeo, Stanford University, Stanford, CA

Vandenbosch, M. B., C. B. Weinberg. 1995. Product and price competition in a two-dimensional vertical differentiation model. *Marketing Science*, **14**(2) 224-249

Waterson, M. 1989. Models of product differentiation. *Bulletin of Economic Research*, **41**(1) 1-27