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The Impact of an Integrated Marketing and Manufacturing Innovation

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Suppose you are a Marketing Manager envisioning a new product, or an Operations Manager contemplating a process improvement, or a CEO who commissioned an integrated new product development team. If our assumptions hold, our model offers you a single numerical measure, called the *degree of product/process innovation*, to determine your initiative's impact on potential sales, prices, market segments, and profits. Our simple, single-period model is a variation of the existing vertically differentiated products model: There are two competing substitute products, and customers will buy at most one of them. Our contribution is to allow new relationships between the valuations of the two products by potential customers, and to allow differing unit production costs. We identify equilibrium results when two competing firms each offer one product, and find the profit maximizing result when one (monopolistic) firm offers both products. The new product infringes on the market in one of two ways: *High-end encroachment* results when the new product attracts the best customers (those with the highest reservation prices), while *low-end encroachment* identifies a situation where the new product attracts fringe (lower-end) customers. Low-end encroachment may help explain why an incumbent sometimes fails to recognize the threat of an entrant's product, as we illustrate with an example from the disk drive industry. In short, we offer insight into the value of both a marketing objective (enhancing the product design attributes) and a manufacturing goal (lowering the production cost) in a product and/or process improvement project.
(*Degree of Product/Process Innovation; Low-End Encroachment; High-End Encroachment; Reservation Price; Disruptive Technology; Operations Strategy; Vertically Differentiated Products*)

1. Introduction

Suppose you are a Marketing Manager, envisioning a new product with new attributes or changed values of existing design attributes, targeted at meeting customer needs and wants. For example, you propose a new light bulb having longer life and using less energy. Or, you envision a new insulin delivery device for diabetics based on inhalation of the drug, rather than needle injection. The new product will compete with an existing (old) product also sold by your firm, or by a competitor, as the case may be. You want to know: Will the new product displace the old product, or will the two products be sold in parallel? What are the prices at which the new and old products will sell? Which segments of the market will buy which products, and which segment will not buy at all? What will the profits from each product be?

Alternately, you are an Operations Manager contemplating a process improvement program. For example, you propose a just-in-time (JIT) production

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system using kanban signals, to reduce plant inventory. Or, you envision a design-for-assembly project to reduce the number of parts in the dashboard of the automobile you produce. You want to know: Will this cost reduction initiative increase future plant capacity requirements? That is, will it precipitate a price reduction that in turn increases sales volume? What will the bottom-line increase in profit be? Is this process innovation preferred over the product innovation envisioned by the Marketing Manager?

And what about the CEO's perspective? She wants to maximize the firm's net benefit from any new project. For the new product proposed by marketing, she wants to be sure that the production cost has been adequately considered. Perhaps there are different process technologies that can be used to manufacture the new product, leading to different unit costs. For the cost reduction project, she wonders if there are any marketing considerations. Perhaps the process technologies will have an impact on product attributes. (The JIT innovation might reduce both the mean and variance of delivery lead-times, for example, which customers value. The design-for-assembly initiative might improve reliability, because there are fewer parts to fail.) The CEO might well support forming an integrated team, with representatives from both marketing and operations, to manage the project. We develop a simple model that gives the team a common ground upon which to evaluate a range of alternatives that the project team might consider. Additionally, the model offers a means by which goals can be set for the integrated team, and a means of measuring the performance of the team against these common goals. For example, the team could be asked to design a new product that would totally displace the old, existing product in the market. Our measure of degree of innovation can serve as a good starting point for addressing the trade-offs between manufacturing and marketing issues in this quest.

With our model, we solve for the prices, quantities, and profits for two products, generally assumed to be the new and old products. (In our terminology, the project is said to result in a *new product*, even if the project is process oriented.) The two products may be offered by the same firm, or different firms. For example, an entrant might develop a new product to compete against an incumbent monopolist's old product. Or, a duopolist might simply reduce product cost, giving it a new replacement product to offer against the competitor's old product. Or, a monopolist might develop a new and improved version of its existing old product. If a single firm offers both products, we find the prices that jointly maximize the firm's profits. If different firms offer the two products, we find the unique Nash equilibrium. In the sense that we find the resulting market outcomes without addressing the issue of entry deterrence, our analysis is pertinent to what Eliashberg and Jeulund (1986) call a surprised incumbent.

These solutions are derived from the *reservation price curves* of the two products, developed as follows. We assume a product is described by n dimensions of quality, but customer type is defined by only one dimension. For any given product, the value ascribed to each dimension of quality (i.e., the part-worth) is assumed to be an affine function of customer type. Reservation price (the most that the customer is willing to pay for a product) is the sum of the part-worths. Note that reservation price curves account for both the product characteristics (a higher quality level raises the curve), and the consumer characteristics (changing customer preferences also alter the curve). Each customer buys (at most) one unit; the unit offering the highest positive surplus (reservation price minus sales price). This framework establishes a linear reservation price curve for each product, and a linear demand curve when that product is sold in isolation.

The new product is said to *encroach* on the old product market. That is, a nontrivial new product has a negative impact on the profitability of the old product, whether the old product is marketed by the same firm or by a competitor. Under our model, there are two primary ways in which this encroachment can occur. ***High-end encroachment*** occurs when the new product appeals to the old product's key existing high-end customers (those with the highest reservation prices). ***Low-end encroachment*** occurs when the new product is shunned by the best customers but instead attracts fringe or low-end customers. This result is discussed in relation to Christensen's (1992) observations on the disk drive industry.

We find that the extent to which the new product encroaches on the old product is a function of both product differentiation (i.e., differences in the reservation price curves, which might typically be a concern of marketing), and the degree to which the new product achieves cost control (typically the focus of operations). With our model, the combined impact of these two factors (reservation price curves and costs) can be described by a single parameter, which we call the ***degree of product/process innovation.*** This measure determines market shares and profit ratios for the two products. Thus, as suggested earlier, our model points to the intertwined nature of product and process innovation. That is, competitive advantage may be achieved through any number of possible combinations of product differentiation and cost, and is thus a function of how well the marketing and operations functions have *jointly* performed.

Marketing may be particularly interested in our result that the quest for high market share and high profit share are parallel pursuits: An increase in market share leads to an even more dramatic increase in profitability. (The ratio of the firm's profit relative to the competitor's profit increases with the square of the market share ratio.) Operations may be more interested to see how the model might also be used in isolation in justifying a process innovation: Lower cost improves profitability by a greater amount than would be derived from simply multiplying the increased margin by the existing market share, because of increased market share.

We explain how our approach relates to the literature in §2. In §3, we develop the reservation price framework upon which our model of product competition is built. In §4 we define the degree of product/process innovation. We then use this measure in §5 to determine the equilibrium market structure in several different market settings. Some examples and special cases of our model are illustrated in §6. We conclude with a summary and discussion of results in §7. A summary of notation is given in Appendix I.

2. Relationship to the Literature

Our model is closely related to models of vertical differentiation of substitute products, well recognized within the marketing and economics literatures. These models determine product demand by assuming products are differentiated along one or more dimensions of quality, and by assuming customers differ in their willingness to pay for quality (all customers agree on which product is of higher quality along each given dimension). In other words, customer preferences establish a set of reservation prices for a product, and reservation prices, along with product prices, determine product demand. We adopt a similar framework, but differ in our assumptions regarding the relationships between customer type and willingness to pay.

Early works used the model of vertical differentiation to investigate how market structure impacts product offerings and social welfare, by comparing product qualities and quantities that are sold in monopolistic and competitive settings. See Mussa and Rosen (1978), Gabszewicz and Thisse (1979), Shaked and Sutton (1982), and Itoh (1983). Matthews and Moore (1987) attach a warranty to each product, and proceed to determine the monopolist's optimal offering of quality, warranty, and price. Greenstein and Ramey (1998) use a one-dimensional model to determine which type of market structure generates the greatest returns to product innovation. Their results for product innovation are compared to those of Arrow (1962), who addressed a similar question relative to process innovation. Moorthy (1988) establishes the optimal one-dimensional product quality level for each of two competing firms. Hauser (1988) and Vandenbosch and Weinberg (1995) extend this type of analysis to two dimensions of quality.

In contrast to these works, our model is similar to that of Smith (1986), in that we take the product offerings as given, thereby falling short of identifying optimal product positions. While Smith (1986) focuses on finding the optimal pricing for a new product with quality falling between two other competitive products, we proceed to find the Nash equilibrium prices, quantities, and profits, but for only two products. Further, while he does not restrict his reservation price curves to a linear form as we do, neither does he allow them to cross, as we do.

A key difference between our model and some of the earlier works is that we do not assume all firms face the same relationship between product cost and product quality. We allow firms with similar products to have differing costs (cost can distinguish one firm from another), and allow products with similar costs to be valued quite differently by customers (due to differences in brand equity, or other attributes). Much of the work within the operations field addresses means by which such cost advantage can be achieved. In short, product differentiation can occur along the dimension of cost as well as along the traditional dimension(s) of quality.

One factor that may impact a firm's cost structure is whether it produces only when firm orders are received, or whether it produces per some other schedule and holds inventory. Eliashberg and Steinberg (1991) examine production and pricing decisions when competitors take asymmetric approaches in this regard and experience a demand surge, but do not focus on how differences in product features or attributes affect the outcome.

We only consider the market impact during a single period immediately following a new product introduction. Eliashberg and Jeuland (1986) additionally include the period prior to introduction in their analysis, in part to examine how anticipated entry of a competitor affects the monopolist's pricing in the two periods. While they utilize a parameter that accounts for the degree of differentiation between products, they do not focus on explicitly measuring this degree of product differentiation, as we do based on reservation price curves and costs. However, some of our results are qualitatively similar (e.g., that lower product differentiation drives prices toward cost).

For a more comprehensive discussion of the literature on product differentiation, see Waterson (1989), Lancaster (1990), and Ratchford (1990). We discuss how conjoint analysis is related to our work in the next section, where we develop the model.

3. Linear Reservation Price Model

Our model results when there is only one dimension of customer type, and customer preferences for each dimension of quality are affine in customer type (see §3.1). Our model also results under certain conditions when monopolistic demand curves are linear (see §3.2).

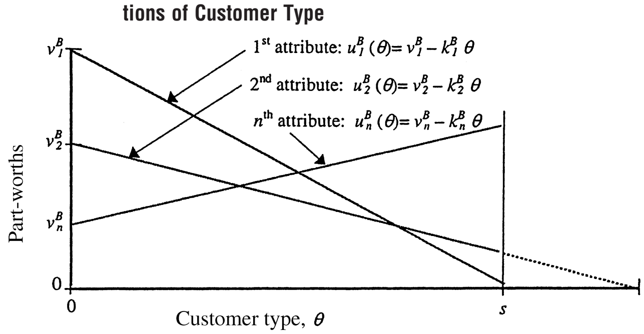
3.1. Translating Multiple Dimensions of Quality Into Reservation Prices

We assume a product can be described by n key attributes, or dimensions of quality. For example, say we are comparing bicycle pumps, for which the key attributes (excluding price) are inflation time, ease-of-use, size, and durability. We assume there is a single dimension that describes customer type, denoted by θ, with a uniform distribution of customers over θ in the interval $[0, S]$. The first product will be denoted as product B, and the second as Product N (notation will be clarified shortly). We denote customer utilities (part-worths) for Product B along the n dimensions by $u_1^B(\theta)$, $u_2^B(\theta)$, . . . , $u_n^B(\theta)$. We assume part-worths are described by affine relationships (see Figure 1), such that the part-worth for product B along dimension one is $u_1^B(\theta) = v_1^B - k_1^B\theta$, where v_1^B denotes the product's part-worth for a customer of type zero and k_1^B denotes the rate of decline in part-worth as customer type increases from 0 to S.

As shown in Figure 1, the first attribute might appeal most highly to a market segment of customers with low θ, the second attribute might be viewed more uniformly across customer types, and the n^{th} attribute might appeal primarily to customers with higher θ. Increasing the quality level of an attribute would shift that attribute's curve upward in some fashion (see §6 for examples). The assumption of affine part-worth curves is at best an approximation in that, for example, part-worths might actually be highest for customers with mid-level θ, but we would not be able to represent that with our model.

A customer's reservation price, also called utility

Figure 1 **Part-Worths for the Attributes are Assumed to be Affine Functions of Customer Type**

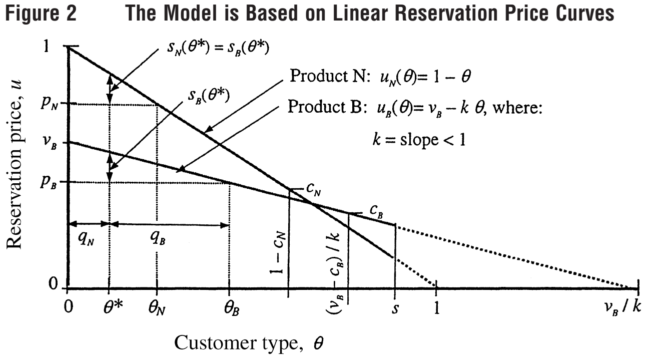


and denoted by $u(\theta)$, is assumed to be the sum of her part-worths. Let $v_B = v_1^B + v_2^B + \ldots + v_n^B$, and let $k_B = k_1^B + k_2^B + \ldots + k_n^B$. We assume, without loss of generality, that v_B and k_B are positive. Thus product B's reservation price curve is affine,[1] given by: $u_B(\theta) = v_B - k_B\,\theta$.

We build Product N's reservation price curve in a similar fashion, with k_N denoting the slope. We deal only with the case where k_N is of the same sign as k_B, and our language applies specifically to this case. However, we credit a reviewer for noting that the alternate assumption leads to some interesting observations: When the slopes k_B and k_N are of different sign, products are designed for opposite ends of the market and may even both achieve full monopoly positions simultaneously. If the products do *not* both achieve monopoly positions, then each product encroaches on the other product's low-end market (the profit otherwise derived from each product is reduced), and every potential customer makes a purchase. The case we focus on in this paper, where k_N and k_B are of the same sign, is in a sense more competitive in that every new product of any consequence will encroach on the competitive product in some fashion.

Without loss of generality, the product labeling has been done such that the product whose reservation price curve has the steeper slope is Product N, for ***niche appeal,*** and the product associated with the flatter slope is Product B, for ***broad appeal.*** See Figure 2. The

Figure 2 The Model is Based on Linear Reservation Price Curves



[1]The assumption that reservation price curves are linear can be relaxed somewhat—the curve need only be linear for prices above cost, and decreasing elsewhere. However, for ease of exposition, we assume linearity throughout.

idea is that there is a relatively small number of customers who value Product N much more than most other customers (before taking price into account), while there is a broad segment of customers who value B about the same amount. We make no assumptions as to whether the reservation price curves cross, which one lies above the other, whether Product B will have the larger market share (as that depends also on units costs), or which is the older product.

Our subsequent analysis will focus on the share of customers perceiving Product N to have positive value, rather than raw market size. Thus, we normalize the scale of the customer types, so that a customer type of one is associated with a reservation price of zero for Product N (if the reservation price curves do not intercept the x-axis, they are extended to do so). The rescaled interval of *actual* customer types is denoted as $[0, s]$. We assume $s \le \min(v_B/k, 1)$.

Let the maximum reservation price for Product N be normalized to one, and scale v_B appropriately. Thus, the slope of Product N's reservation price curve is negative one (because all slopes are negative, we subsequently refer to their absolute values as the slopes, for convenience). The slope of Product B's reservation price curve can now simply be denoted by k (k is the ratio of the slopes of the unnormalized reservation price curves). We assume $k \ne 1$ (thus, by definition, $0 < k < 1$). If k is close to one, then the two curves have about the same breadth of appeal (the curves are nearly parallel) and if k is close to zero, they have very different breadths of appeal. We shall show that market equilibrium prices, quantities, and profits are functions of k. Under these assumptions, reservation prices are given by:

$$u_N(\theta) = 1 - \theta, \text{ and} \tag{1}$$

$$u_B(\theta) = v_B - k\,\theta. \tag{2}$$

We assume total production costs are linear in volume, with marginal costs denoted by c_N and c_B. A product's marginal cost is assumed to be between its minimum and maximum reservation prices. We make no assumptions as to the specification of costs, but illustrate in §6.3 a model of the form $c = \alpha(\beta_1\,q_1^2 + \beta_2\,q_2^2 + \ldots + \beta_n\,q_n^2)$, where α is a firm-specific parameter, β_i is a cost coefficient specific to Attribute i, and q_i is the attribute "quality."

Thus, our model is similar to the one-dimensional models of vertical differentiation as developed by Moorthy (1988) and Musa and Rosen (1978), in that we assume linear reservation price curves. However, we relax the assumption that a particular customer type holds a zero reservation price for all products (i.e., we relax the assumption of a common x-intercept).

3.2. Conditions Under Which the Model Replicates Linear Monopolistic Demand Curves

Our model also represents certain situations where each product faces a linear demand curve, should that product be sold in a monopoly. To see this, interpret the monopolist's demand curve as a plot of the reservation prices for a sequence of potential customers. This sequence implicitly defines customer types, where a type $\theta = 0$ customer holds the highest reservation price and the scale runs up to the total number of potential sales. Thus, we use the terminology *customers*, and *customer type* interchangeably with the potential sales as given on the demand curve. For the second product, again consider the demand curve it faces if sold in isolation (even though ultimately, multiple products may be offered). We assume this demand curve is linear, and similarly create from it the reservation price curve. If the resulting sequence of customers is the same for both products, then the reservation price curves are of the form we assume.

Note that a linear reservation price curve may also represent a market where individuals are willing to buy multiple units. One of many possible examples would be where an individual's reservation price for the first unit corresponds to customer type 0, her reservation price for the second unit corresponds to customer type 37, her third potential unit purchased corresponds to type 103, and so on. Other individual's potential purchases would also be represented by sequences of distinct customer types.

Some examples in which our assumptions might hold are discussed in §3. Additionally, we discuss below the possibility that our model might be used as an approximation in more complex situations, to perform exploratory analysis.

3.3. The Model as an Approximation of Conjoint Analysis

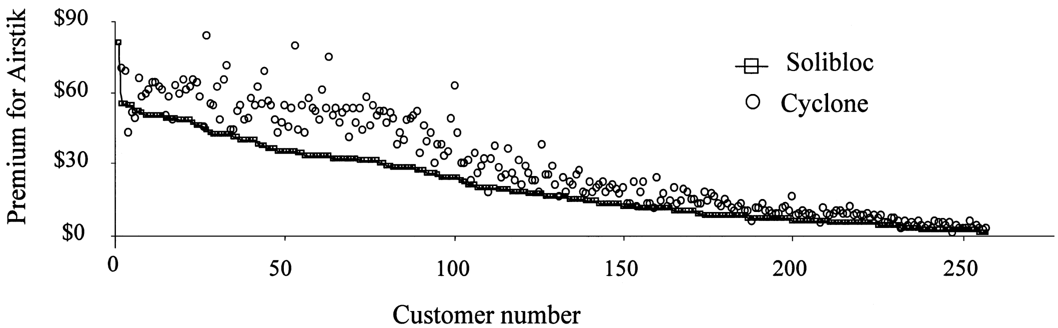
In practice, it may be possible to approximate a product's reservation price curve from something akin to conjoint analysis. Conjoint is a survey technique that has been widely used in practice to estimate the market share for each of multiple possible competing substitute products with given prices (see Green and Srinivasan (1978, 1990) for pertinent surveys).

One way of implementing conjoint, called full profile conjoint analysis, is to ask potential customers to rank order their preferences for multiple potential products. From this ordering, each customer's relative utility function for each key attribute is inferred. A given product's quality along each dimension determines the customer's utility, or part-worth, for that dimension, and the sum of the part-worths yields her total (relative) utility for that product. The customer is presumed to purchase the product giving her the highest total utility.

If the customer ranking includes the choice of buying nothing, then we can translate the part-worths into monetary units, and the sum of the part-worths, excluding the price part-worth, would be equated with that individual's reservation price. If we order the customers from the one who holds the highest reservation price for a product to the one with the lowest, we obtain the product's reservation price curve, which we have assumed to be linear. Maintaining this same ordering of customers we plot the second product's reservation price curve. In practice, this second curve may be highly discontinuous. However, we assume it is also linear.

One might hypothesize that the deviation from linearity grows with the number of key attributes (dimensions of quality). For the case of bicycle pumps and the previously ascribed four dimensions (excluding price), we are able to do a rough sanity check on our linearity assumptions, using data from Dahan and Srinivasan (2000). In their sampling of 256 customers, they did not offer a choice of "buying nothing" and, hence, the data are not rich enough to develop full reservation price curves. However, we are able to estimate the price premium that each customer would be willing to pay for one model of pump over another (i.e., the difference between each customer's reservation prices for the two pumps). For example, Figure 3 shows the premiums for a high-end commercial product, Airstik, over two other products. Customers are sorted in order of Airstick's premium over Solibloc (a

Figure 3 **Premiums for the Airstik Bike Pump Over Two Others, Solibloc and Cyclone**



lower-end commercial product), such that this set of premiums is represented by the downward sloping solid curve. Suppose that we make the rather grand assumption that this sequence of customers also gives the sequence of highest reservation price to lowest for one of the products. If this assumption holds, (and if we assume, as might be done in a conjoint analysis, that each sampled individual represents an equal fraction of the potential market), then the premiums should plot as a straight line. The result does appear to be reasonably well approximated by a straight line (with the exception of the first customer).

The next check is interesting. Keeping the sequence of customers the same, we plot the price premium when comparing Airstik to another model, Cyclone. Again, if our assumptions were to hold, we would also see this plot as a straight line. Figure 3 reveals a scatter plot, rather than a straight line. However, one might argue that a straight line might be a good enough fit to do exploratory analysis such as what is described in this paper. The potential advantage of our approach over conjoint analysis is that we are able to derive the market outcomes analytically, whereas conjoint analysis is typically used in conjunction with a case-by-case market simulation.

Obviously, this sanity check is entirely inadequate as an empirical test of our model. However, it suggests that further empirical research is warranted. Regardless of the results of such work, conjoint simulation remains more appropriate for a field application where a high fidelity estimate of the market impact is imperative, while our approach is at best a modeling tool that can be used to pursue insights, such as the strategic importance of simultaneous product and process improvements. In essence, we intend our approach to be used at an earlier stage of the development process and at a higher, more strategic level within the firm.

3.4. Market Segments as a Function of Price

Let p_N and p_B denote sales prices, let $p = (p_N, p_B)$ denote the vector of prices, and let q_N and q_B denote sales quantities. Let $\theta_N = \theta_N(p)$ denote the type of customer who is indifferent between Product N and nothing: $\theta_N \equiv 1 - p_N$. Similarly, let $\theta_B = \theta_B(p)$ denote the type of customer who is indifferent between Product B and nothing: $\theta_B \equiv (v_B - p_b)/k$. That is, θ_N and θ_B denote customer types for whom $u_N(\theta_N) = p_N$, and for whom $u_B(\theta_B) = p_B$, respectively (without conditions on the prices, these points may land outside the range of *actual* customer types).

We make the standard assumption that the old and new products are economic substitutes in that a customer will purchase at most one product, the product offering the highest positive ***surplus***, where surplus is the difference between the customer's reservation price and the sales price. Let $s_N(\theta)$ and $s_B(\theta)$ denote surpluses: $s_N(\theta) = u_N(\theta) - p_N = (1 - \theta) - (1 - \theta_N) = \theta_N - \theta$, and $s_B(\theta) = u_B(\theta) - p_B = (v_B - k\,\theta) - (v_B - k\,\theta_B) = k\,(\theta_B - \theta)$. As indicated earlier, a customer buys only the product with the highest positive surplus. Let $\theta^* = \theta^*(p)$ denote the type of customer who is indifferent between buying Product N and buying Product B, if such a customer exists. By definition, $s_N(\theta^*) = s_B(\theta^*)$, therefore $\theta_N - \theta^* = k\,(\theta_B - \theta^*)$. Rearranging terms yields $\theta^* = (\theta_N - k\,\theta_B)/(1 - k) = [(1 - p_N) - (v_B - p_B)]/(1 - k)$. If $0 \le \theta^* \le \theta_N$, then θ^* lies within the range of actual customer types. Note that if $\theta^* = 0$, then $\theta_N = k\,\theta_B$, and if $\theta^* = \theta_N$, then $\theta_N = \theta_B = \theta^*$.

In Theorem 1 we identify the sales quantities, given the vector of sales prices. Later in Theorem 2 we provide the equilibrium prices when one firm offers Product N and the other offers B, and in Theorem 3 we provide the optimal prices when one firm offers both products.

THEOREM 1. *Given the vector of sales prices $p = (p_N, p_B)$, sales quantities q_N and q_B are determined by $\theta_B = \theta_B(p)$, $\theta_N = \theta_N(p)$, and $\theta^* = \theta^*(p)$ as follows:*

(a) If $\theta_B \le \theta_N$ (i.e., if $\theta^* \ge \theta_N$), then $q_N = \theta_N = (1 - p_N) \ge 0$, and $q_B = 0$.

(b) If $\theta_N \le \theta_B \le \theta_N/k$ (i.e., if $0 \le \theta^* \le \theta_N$), then $q_N = \theta^* = [(1 - p_N) - (v_B - p_B)]/(1 - k) \ge 0$, and $q_B = \theta_B - \theta^* = [(v_B - p_B) - k(1 - p_N)]/[k(1 - k)] \ge 0$.

(c) If $\theta_B \ge \theta_N/k$ (i.e., if $\theta^* \le 0$), then $q_N = 0$ and $q_B = \theta_B = (v_B - p_B)/k \ge 0$.

All proofs are given in Appendix II.

Theorem 1 says that if both products are sold in positive quantities, then customers in the interval $(0, \theta^*)$ buy Product N, while those in the interval (θ^*, θ_B) buy Product B. Note that customers with low θ (the customers who buy Product N) represent the "best" customers, in the sense that these customers are willing to pay higher prices for the products as compared to customers with higher θ. Thus, if both products are sold, the implication (as stated formally in Corollary 1 below) is that the best customers always buy Product N.

COROLLARY 1. *Customers who purchase Product N are better customers (have lower type indices) than those who purchase Product B.*

Managerial implications are discussed in conjunction with the examples of §6.

4. The Degree of Product/Process Innovation

We now develop a measure of how superior (or inferior) Product N is to Product B, and vice versa. We call this measure of superiority (or inferiority) the ***degree of product/process innovation***, denoted by D. We shall show that this factor D is quite informative in that it establishes sales prices, quantities, market shares, and profit shares.

The measure D takes one of two forms. When D describes the degree of innovation of Product N relative to B it is denoted as D_N, and when it describes the degree of innovation of Product B relative to N it is denoted as D_B. The definitions are:

$$D_N \equiv (1 - c_N)/(v_B - c_B), \tag{3}$$

$$\text{and } D_B \equiv (v_B - c_B)/[k(1 - c_N)]. \tag{4}$$

Note that $D_B = 1/(D_N k)$: We say that D_B is the converse of D_N. If the two products are identical (with identical costs), then $D_B = D_N = 1$. However, if $D_N = 1$ (or $D_B = 1$), the reservation prices (and physical characteristics) of the products may be quite different. In other words, both product differentiation (reservation prices) and product cost are intertwined in calculating D, just as they are both factors in determining the actual market outcome.

4.1. The Intertwined Nature of Product Innovation and Process Innovation

Consider two products with identical product features (and reservation prices), but with different costs. From our perspective, the lower-cost is a result of pure process innovation, which is invisible to the customer, except for a possible change in price. Process innovation may be something as simple as reducing the time of one assembly step on the production line. Or, it may be as complex as Kodak's switch from the production of film by the batch method to continuous production, as discussed by Utterback (1994). In reality, pure process innovation (as we define it) is rare, because a process change will generally also change some attribute of the product, such as its conformance quality. For example, an auto manufacturer might use design-for-assembly to reduce the number of parts in the dashboard. Because the new design has fewer parts that can fail, it may also be more reliable. See Boothroyd (1992).

We view product innovation as something that changes the product features or attributes, altering the reservation price curve. Product innovation may be something as simple as offering a postage stamp with a peel-off backing instead of one that needs to be licked, or as complex as developing a futuristic electric vehicle that replaces the gasoline-powered automobile. *Pure* product innovation would presumably leave cost unchanged. However, in practice, new features generally require process changes. A process change may be the substitution of Part "x" for "y" in an assembly sequence, a change in color, or a new product advertisement (we take the broad view that the process encompasses all steps involved in presenting the product to the customer).

In short, product innovation and process innovation are innately intertwined. Studies touting the advantages of simultaneous product and process engineering (e.g., Krishnan, Eppinger, Whitney (1997)) support this perspective. Note how D_N and D_B reflect this integrated perspective, by capturing the combined effects of product and process innovation in one simple measure. By the definitions of D_N and D_B, a product with fewer features (lower reservation prices) might be superior if its cost is sufficiently low. Alternately, a product with higher cost might be superior if it has extra features that are highly valued by customers.

5. Equilibrium Market Structure, Prices, Quantities, and Profits

We first consider the situation where one firm markets Product N, and a second firm offers B. We then consider the situation where only one firm markets both products. See Schmidt (1998) for the solution to a third situation involving, effectively, three products and two firms. (When we say that a firm offers or markets a product, we do not require sales to be strictly positive. The pricing of the differentiated product may push the product's sales to zero.)

5.1. One Firm Offering Only Product N, a Second Firm Offering Only Product B

If one firm offers only Product N, and a second firm offers only Product B, the market outcome may be a monopoly for one of the products, a ***differentiated duopoly*** (a market where two firms each sell one product, differentiated from the competitor's product), or a ***constrained monopoly*** for one of the products. In a constrained monopoly, only one firm realizes strictly positive sales, but the firm is constrained to charging something less than the monopoly price. Under our assumption of price competition, a firm is always willing to undercut the competitor as long as price does not fall below cost. Thus, the constrained monopolist faces a competitor who prices at cost, but who realizes no sales. (Our terminology for market structure follows Greenstein and Ramey (1998).)

Firms are assumed to simultaneously set prices to maximize profits, denoted as π_N and π_B. In other words, each firm determines its best pricing response, given the price set by the competitor for the other product. The market outcome, as given in upcoming Theorem 2, is determined by D. It is assumed D is not identically equal to $2/k$, $(2 - k)/k$, $1/k$, 1, or ½, to avoid possible multiple outcomes at those boundary points.

As Theorem 2 shows, there are certain cutoff points that establish where the market changes. To aid in interpreting the regions between cutoff points, we say a product represents ***drastic*** innovation if $D > 2/k$, ***extensive*** innovation if $(2 - k)/k < D < 2/k$, ***moderate*** innovation if $1/k < D < (2 - k)/k$, and ***negligible*** innovation if $1 < D < 1/k$.

Recall that $D_B = 1/(D_N k)$. Thus, if $D_N > 2/k$, i.e., if Product N represents drastic innovation, then $D_B <$ ½, and Product B (which we denote as the converse product) is said to be ***drastically inferior***. Similarly, if one product represents extensive innovation, then the second product is ***extensively inferior,*** with ½ $< D < 1/(2 - k)$, and if one product represents moderate innovation, then the second product is ***moderately inferior,*** with $1/(2 - k) < D < 1$. Negligible innovation is its own converse (a negligible innovation is also negligibly inferior).

Given this terminology, we summarize Theorem 2: (1) If a product represents drastic innovation, then it achieves a monopoly; (2) If a product represents extensive innovation, then it sells in a constrained monopoly; and (3) If one of the products represents moderate or negligible innovation, then both products are sold in a differentiated duopoly. The result that drastic innovation achieves a monopoly coincides with the standard economic definition of drastic innovation, as given in Arrow (1962), for example.

D **Defines a Product's Profit Potential.** Using Theorem 2, we find that D is an indicator of how close the firm comes to achieving monopoly profit, in spite of the competitive product. See Figure 4 (if the profit ratio for Product N is desired, substitute D_N for the dummy

Theorem 2. *When one firm offers Product N and a second firm offers Product B, the market structure represents a unique Nash equilibrium outcome, as determined by D. Prices, quantities, and profits are as follows.*

Market	Conditions	Product N	Product B
Monopoly for Product N	If: $D_N > 2/k$, that is, if: $D_B < 1/2$), then:	$p_N = (1 + c_N)/2$ $q_N = (1 - c_N)/2$ $\pi_N = (1 - c_N)^2/4$	$p_B \geq c_B$ $q_B = 0$ $\pi_B = 0$
Monopoly for Product B	If: $D_N < 1/2$, that is, if: $D_B > 2/k$, then:	$p_N \geq c_N$ $q_N = 0$ $\pi_N = 0$	$p_B = (v_B + c_B)/2$ $q_B = (v_B - c_B)/(2k)$ $\pi_B = (v_B - c_B)^2/(4k)$
Constrained Monopoly for Product N	If: $(2 - k)/k < D_N < 2/k$, that is, if: $½ < D_B < 1/(2 - k)$, then:	$p_N = [k - (v_B - c_B)]/k$ $q_N = (v_B - c_B)/k$ $\pi_N = [k(1 - c_N) - (v_B - c_B)]\,(v_B - c_B)/k^2$	$p_B = c_B$ $q_B = 0$ $\pi_B = 0$
Constrained Monopoly for Product B	If: $½ < D_N < 1/(2 - k)$, that is, if: $(2 - k)/k < D_B < 2/k$, then:	$p_N = c_N$ $q_N = 0$ $\pi_N = 0$	$p_B = v_B - (1 - c_N)$ $q_B = (1 - c_N)/k$ $\pi_B = [(v_B - c_B) - (1 - c_N)](1 - c_N)/k$
Differentiated Duopoly	If: $1/(2 - k) < D_N < (2 - k)/k$, that is, if: $1/(2 - k) < D_B < (2 - k)/k$, then:	$p_N = [2(1 + c_N) - (v_B - c_B) - k]/(4 - k)$ $q_N = [(2 - k)(1 - c_N) - (v_B - c_B)]/[(4 - k)(1 - k)]$ $\pi_N = [(2 - k)\,(1 - c_N) - (v_B - c_B)]^2/[(4 - k)^2\,(1 - k)]$	$p_B = [2(v_B + c_B) - k(1 - c_N) - k\,v_B]/(4 - k)$ $q_B = [(2 - k)\,(v_B - c_B) - k(1 - c_N)]/[k(4 - k)(1 - k)]$ $\pi_B = [(2 - k)\,(v_B - c_B) - k(1 - c_N)]^2/[k(4 - k)^2\,(1 - k)]$

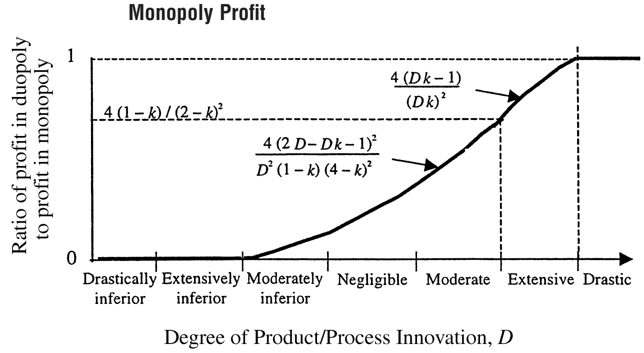
parameter D, while if the ratio for B is desired, substitute D_B). Note, for example, that a moderately inferior product generates little profit but dramatically cuts the profit of the moderately superior product. Also, if the two products represent negligible innovation relative to each other, they each receive quite modest profit relative to the monopoly level.

These results suggest why one company might buy out another that introduces a moderately inferior innovation: The new product doesn't sell after being bought (we show this in the next section), but the incumbent firm still buys it out because of the detrimental effect it would have had if sold by the competitor. (This paper has not focused on the consumers' perspective, but they would prefer the competitive situation since it offers higher consumer surplus.)

D **Establishes Market Shares and Profit Shares.** The model also allows us to examine market share and profit relationships, which may be difficult to study empirically.

Corollary 2. *When both products are sold by competitors in strictly positive quantities (i.e., for $1/(2 - k) < D < (2 - k)/k$), the market share and profit share ratios, as calculated from Theorem 2, are:*

Figure 4 *D* **Determines How Close the Product Comes to Achieving Monopoly Profit**



$$q_N/q_B = k[(2 - k)\,D_N - 1]/[(2 - k) - k\,D_N],$$

$$\pi_N/\pi_B = k[(2 - k)D_N - 1]^2/[(2 - k) - k\,D_N]^2,$$

$$q_B/q_N = [(2 - k)D_B - 1]/[(2 - k) - k\,D_B], \text{ and}$$

$$\pi_B/\pi_N = k[(2 - k)D_B - 1]^2/[(2 - k) - k\,D_B]^2.$$

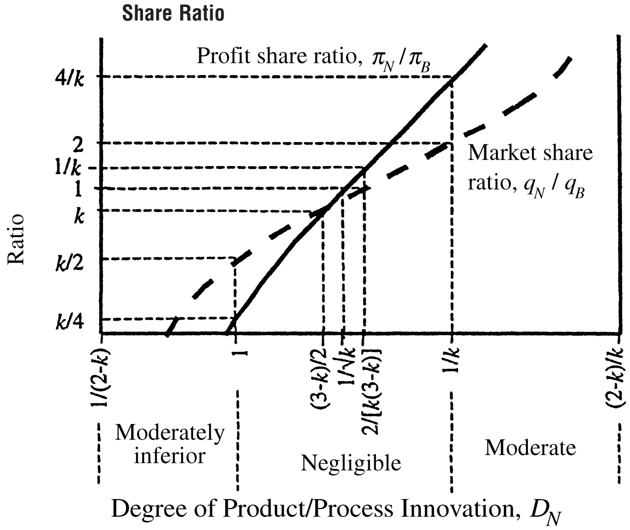
Note that the profit share ratio is proportional to the square of the market share ratio: $\pi_N/\pi_B = (1/k)\ (q_N/q_B)^2$ and $\pi_B/\pi_N = k\ (q_B/q_N)^2$. Hence, the firm that achieves a high market share attains an even greater proportion of the total market profits (see Figure 5).

These results suggest the benefit from cost reduction can be much more significant than a naïve calculation (multiplying the increased margin by the sales volume) might suggest. For example, if you offer Product N and reduce cost c_N, you increase D_N, by Equation (3). Say this increases your market share ratio by 10%. Your corresponding increase in the profit share ratio is 21%! Similar comments could be made relative to the benefits of product feature enhancements, because these would elevate the reservation price curve and similarly increase D_N.

5.2. Only One Firm Offering Both Products N and B

If only one firm offers both Products N and B, then either the firm has a monopoly with product N, or with B, or the firm has a ***joint monopoly,*** selling both products. The result is again determined by D (see Theorem 3), summarized as follows: (1) If one of the products represents drastic, extensive, or moderate innovation, then the market is a monopoly for that product; and (2) If the products represent negligible innovation relative to each other, then the market is a joint monopoly, with the firm offering both products at monopoly prices.

Figure 5 **The Profit Share Ratio Increases with the Square of Market Share Ratio**



Recall that when one firm sold Product N and another sold B, there was a wider range over which both products were sold (the differentiated duopoly spanned the regions of moderate and negligible innovation, and their converses). When only one firm is involved, both products are sold only if they represent negligible innovation relative to each other (see Figure 6).

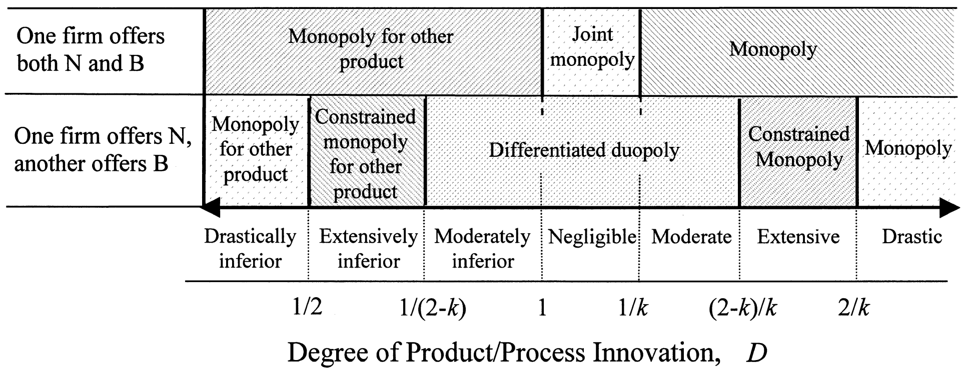
Note that Figure 6 is valid for any pair of products, where each product is described by its reservation price curve and its cost. That is, it is valid for the entire range of parameters. For example, say the incumbent and an entrant pursue similar new products but have different production costs. Specifically, assume the incumbent and an entrant are working on new product B, for which $v_B = 0.8$ and $k = 0.81$. Assume the incumbent's cost will be 0.71, and the entrant's cost will be 0.5, while the incumbent's old Product N has a cost $c_N = 0.9$. If only the incumbent succeeds in developing the new product, we find $D_B = D_N = 1/\sqrt{k}$, such that the incumbent sells both new Product B and old Product N in a joint monopoly. If only the entrant succeeds, we find $D_B = 3/k$ and $D_N = 1/3$, indicating the entrant has a monopoly with its new Product B. See Schmidt (1998) for solutions when both firms succeed.

6. Examples Showing Contrasting Market Outcomes

We now explore some special cases of our model, illustrating that a new product impacts an existing market in one of two key ways. Under ***high-end encroachment,*** the new product steals some of the incumbent firm's best customers (those with relatively higher reservation prices). Under ***low-end encroachment,*** the new product sells to low-end customers (those with lower reservation prices), possibly creating a new market segment.

Under the usual specification of one-dimensional vertical product differentiation, a new product of higher quality always results in high-end encroachment. Our formulation differs in that a new, higher quality product can result in either high- or low-end encroachment, as we shall illustrate. Then to further

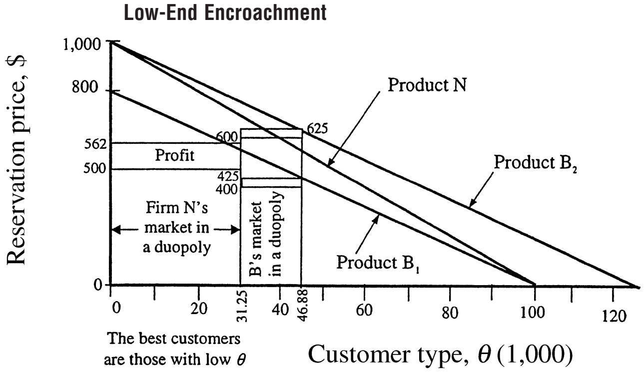
Figure 6 **Market Structure, as Determined by the Degree of Product/Process Innovation**



Theorem 3. *When only one firm offers both Product N and Product B, market structure, prices, quantities, and profits are determined by D as follows.*

Market	Conditions	Product N	Product B
Monopoly for Product N	If: $D_N > 1/k$, that is, if: $D_B < 1$, then:	$p_N = (1 + c_N)/2$ $q_N = (1 - c_N)/2$ $\pi_N = (1 - c_N)^2/4$	$p_B \geq v_B - k(1 - c_N)/2$ $q_B = 0$ $\pi_B = 0$
Monopoly for Product B	If: $D_N < 1$, that is, if: $D_B > 1/k$, then:	$p_N \geq 1 - (v_B - c_B)/2$ $q_N = 0$ $\pi_N = 0$	$p_B = (v_B + c_B)/2$ $q_B = (v_B - c_B)/(2\,k)$ $\pi_B = (v_B - c_B)^2/(4\,k)$
Joint Monopoly	If: $1 < D_N < 1/k$ that is, if: $1 < D_B < 1/k$, then:	$p_N = (1 + c_N)/2$ $q_N = [(1 - c_N) - (v_B - c_B)]/[2(1 - k)]$ $\pi_N = (1 - c_N)\,[(1 - c_N) - (v_B - c_B)]/[4(1 - k)]$	$p_B = (v_B + c_B)/2$ $q_B = [(v_B - c_B) - k(1 - c_N)]/[2k(1 - k)]$ $\pi_B = (v_B - c_B)\,[(v_B - c_B) - k(1 - c_N)]/[4k(1 - k)]$
		$\pi_N + \pi_B = [k(1 - c_N)^2 - 2k(1 - c_N)(v_B - c_B) + (v_B - c_B)^2]/[4k(1 - k)]$	

Figure 7 **Reservation Price Curves for the Examples of High-End and Low-End Encroachment**



illustrate the case of low-end encroachment, we use an example from the disk drive industry.

6.1. High End Encroachment—The Case of One Dimensional Vertical Differentiation

If the reservation price curves have the same x-intercept, then our model reduces to linear, one-dimensional vertical product differentiation, as described by Moorthy (1988), for example. To illustrate, assume an incumbent monopolist offers microprocessor B_1. Assume there are 100,000 potential customers (see Figure 7), the maximum reservation price is $v_{B_1} =$ \$800, and cost is $c_{B_1} =$ \$400. The price is $p_{B_1} =$ \$600, with $q_{B_1} =$ 25,000 units sold to customers of type $0 \leq$

$\theta \leq 25{,}000$ resulting in a monopoly profit of $\pi_{B_1} = \$5$ million.

Now assume an entrant introduces a new, faster microprocessor N (the only thing customers care about is processing speed). Assume N's maximum reservation price is $v_N = \$1{,}000$, the total potential market remains at 100,000, and cost is $c_N = \$500$. In the resulting differentiated duopoly, the incumbent loses all of its previous customers to the entrant, who also picks up some additional customers ($q_N = 31{,}250$, $p_N = \$562.50$, and $\pi_N = \$1.95$ million). The incumbent picks up customers in the interval (31,250, 46,880) who previously bought nothing ($q_{B_1} = 15{,}630$, $p_{B_1} = \$425$, and $\pi_{B_1} = \$390{,}000$). Thus, the entrant's new product reduces the incumbent's profit by over 90%, while total units sold nearly doubles.

Customers with low θ are the best customers, in that they are willing to pay the most for *either* product. Moorthy (1988) confirms that, under this one-dimensional form of vertical product differentiation, the higher quality product always sells to the best customers. In our terminology, this type of a new, higher quality product results in high-end encroachment.

We could also speak of high-end encroachment when the new, faster microprocessor is introduced by the *same* firm, rather than by a competitor. When Intel introduces, say, the Pentium III, this product is bought by high-end customers, at a high price. The Pentium II shifts to selling to a lower market segment. (Our model says nothing about *why* a firm might introduce a new product that encroaches on its own old product, but merely gives the market impact.)

6.2. Low-End Encroachment

Alternately, begin by assuming the incumbent sells microprocessor Product N (continue to refer to Figure 7). In a monopoly, $p_N = \$750$, $q_N = 25{,}000$ (sales are to customers of type $0 \leq \theta \leq 25{,}000$), and $\pi_N = \$6.25$ million. One form of low-end encroachment might occur if the incumbent (or a competitor) introduces a new, slower (lower quality) microprocessor Product B_1, with cost $c_{B_1} = \$400$ as before. For example, Intel's Celeron chip might expand the market for sub \$1000 personal computers, while the older but faster chip keeps the higher-end customers.

However, another interesting case might be if the entrant introduces Product B_2, for which $v_{B_2} = \$1{,}000$, and $c_{B_2} = \$600$. Microprocessor B_2 is of higher quality in that every customer's reservation price is higher. However, its attractiveness lies primarily with low-end customers, and it increases potential market size to 125,000. (Maybe B_2 is the same speed as N, but includes training, of little interest to high-end users.) Even though the entrant introduces a higher quality product, the incumbent Firm N keeps all of its customers and adds a few more ($q_N = 31{,}250$ and $p_N = \$562.50$). The entrant encroaches on the low-end, effectively creating a new market ($q_{B_2} = 15{,}620$, $p_{B_2} = \$625$ and $\pi_{B_2} = \$390{,}000$). Compared to the previous example, the new product has a less detrimental, but still very significant effect on the incumbent, whose profit drops by 69% to $\pi_N = 1.95$ million. Again, the total unit sales nearly double.

Thus with our model, we see that low-end encroachment occurs whenever the new product is Product B, even if Product B is of higher quality. Conversely, high-end encroachment occurs when the new product is Product N. (At one extreme, when innovation is extensive or drastic, encroachment results in the new product taking the entire market. At the other extreme, when innovation is extensively or drastically inferior, encroachment yields no sales.)

These examples were presented primarily to distinguish between high- and low-end encroachment, and show why higher quality does not always imply the high-end version in our model, as it does with single-dimensional vertical differentiation. We next look at the disk drive industry, to show how Christensen's (1997) story about disruptive technology might be interpreted within our framework of low-end encroachment.

6.3. Low-End Encroachment in the Disk Drive Market

As described by Christensen (1992), two primary dimensions of quality for disk drives are capacity and compactness. Other things being equal, all customers prefer higher storage capacity, and all prefer smaller physical size. But his regressions showed that the value placed on storage capacity *increased* monotonically with the customer's system size (from portable

PCs to desktops to mid-range computers to mainframes), while the value placed on compactness *decreased* with system size.

We model the disk drive market as follows. Let θ denote customer type, with mainframe customers characterized by the interval $(0, \theta_1)$, mid-range customers by (θ_1, θ_2), desktop customers by (θ_2, θ_3), and portable PC customers by (θ_3, θ_4), where $\theta_1 < \theta_2 < \theta_3 < \theta_4$. Potential market size is θ_4 (we assume $\theta_4 = 1{,}275{,}000$). Following the convention of §3.1, let k_1 denote the (negative) slope of the part-worth curve for capacity. We assume that as θ increases (as customer system size decreases), the part-worth for a given capacity level *decreases* linearly to zero. (Mainframe customers value capacity the most, portable PC customers the least.) This means $u_1(\theta_4) = 0$, which leads to $u_1(\theta) = k_1(\theta_4 - \theta)$. We denote the capacity level in MB by m and assume every customer prefers more, but has diminishing returns over the range of concern, as given by $k_1 = 0.000376\ m\text{^}0.395$. This results in $u_1(\theta) = (0.000376\ m\text{^}0.395)\ (1{,}275{,}000 - \theta)$.

Next consider the part-worth for compactness. Per §3.1, the part-worth is given by $u_2(\theta) = v_2 - k_2\,\theta$. We assume that at one extreme, a mainframe customer of type zero is indifferent between different sizes: We assume $u_2(0)$ is constant at $v_2 = 1085$. As customer type increases (as we move toward portable PC customers) customers become increasingly more sensitive to size. That is, a more compact drive gives higher utility: For a drive of diameter d, in inches, we assume $k_2 = -0.000348\ \ln(145\ d^{-3})$ over the range of interest (the sign is negative so that k_2 decreases as compactness increases, the term d^{-3} reflects the fact that volume increases roughly with the cube of d and compactness is inversely related to volume, and the logarithmic function models decreasing returns). This results in $u_2(\theta) = 1085 + 0.000348\ \ln(145\ d^{-3})\ \theta$. Reservation price is the sum of the part-worths: $u(\theta) = u_1(\theta) + u_2(\theta)$.

Now consider disk drives N and B, with capacities yielding k_1^N and k_1^B, and compactness yielding k_2^N and k_2^B. We assume $(k_1^N + k_2^N)$ and $(k_1^B + k_2^B)$ are unequal and strictly positive. Without loss of generality, denote the disk drives such that $(k_1^N + k_2^N) > (k_1^B + k_2^B)$. Scale the measures of capacity and compactness, and customer types such that $(k_1^N + k_2^N) = 1$ and $1085 + k_1^N\,\theta_4 = 1$. This yields: $u_N(\theta) = 1085 + k_1^N\,\theta_4 - (k_1^N + k_2^N)\,\theta = 1 - \theta$, Equation (1), and $u_B(\theta) = 1085 + k_1^B\,\theta_4 - (k_1^B + k_2^B)\,\theta$, equivalent to (2), where $\nu_B = (1085 + k_1^B\,\theta_4)/(1085 + k_1^N\,\theta_4)$, and $k = (k_1^B + k_2^B)/(k_1^N + k_2^N)$.

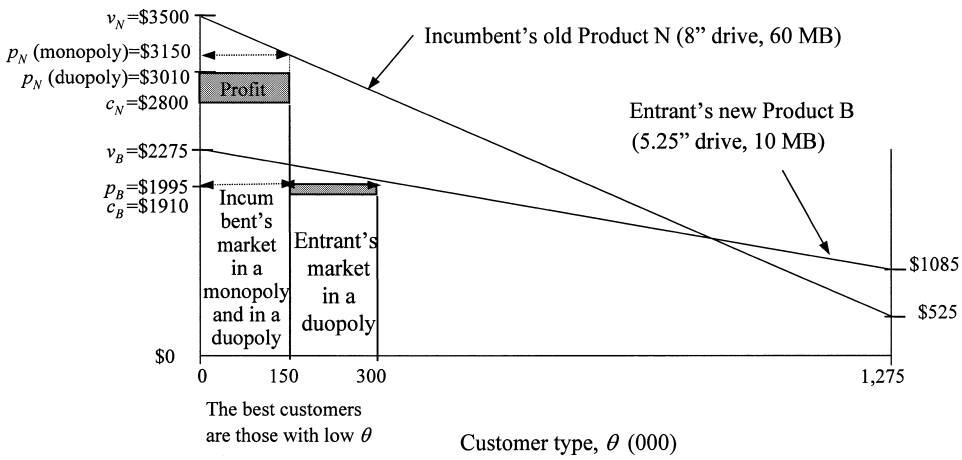
To show with this example how one might explicitly model cost, we assume that for Attribute i, the cost c_i of providing quality q_i is of the form $c_i = \alpha\,\beta_i\,q_i^2$, where α is firm-specific and β_i is attribute-specific. Thus, for this disk drive example, $c = \alpha(\beta_1\,k_1^2 + \beta_2\,k_2^2)$. Here we will assume $\alpha = 1$ for all firms, because we want to focus on how different product attributes can impact the market (the notion of low-end encroachment), rather than focus on how the firms' cost structures impact the market. Further, we take q_1 to be the capacity level in MB and q_2 to be compactness as measured by d^{-3}, and assume $\beta_1 = 0.737$ and $\beta_2 = 38.45 \times 10^6$. (Because in this case the part-worth is a constant for a customer at one end of the continuum, another indicator of the quality of Attribute i is k_i, the slope of that attribute's part-worth curve.)

Between 1975 and 1990, the standard disk drive size (in inches) dropped incrementally from 14 to 8 to 5.25 and finally to 3.5. With each new generation came a new market leader—Storage Technologies, followed by Quantum, Seagate, and, finally, Conner Peripherals. According to Christensen (1997), the incumbent failed to recognize the manner in which the new, smaller-sized drive was encroaching on the mainstream product. The entrant's product did not (initially) appeal to the incumbent's mainstream customers, but rather, appealed to fringe customers. Over time, however, the trajectory of improvements in the smaller drives led to their acceptance by these same mainstream customers.

To gain insight into how these market outcomes might have occurred, consider the following hypothetical situation (see Figure 8). In 1981, an incumbent sells old Product N, an 8 inch disk drive ($k_2^N = 0.000439$) with 60 MB capacity ($k_1^N = 0.00189$), yielding cost $c_N = \$2800$. (While this example is adapted from Christensen (1992), we do not claim to adequately model that market.)[2] The incumbent monopolist sells

[2]The price and storage capacity numbers for our example replicate his Exhibit 4.7, which shows that in 1981 an 8 inch drive with 60 MB capacity sold for \$3,000 and a 5.25-inch drive with 10 MB capacity sold for \$2,000. In our example, after introduction of the new 5.25-

Figure 8 **Example Showing How a New Smaller Disk Drive Might Encroach on the Lower End of the Market, Leaving the Incumbent With All of Its Customers and the Bulk of Its Profit, While the Total Market Size Doubles**



$q_N = 150{,}000$ units at price $p_N = \$3150$ realizing profit $\pi_N = \$52.5$ million, primarily for use in computers of mid-range size or larger.[3]

Now assume that in late 1981 an entrant introduces Product B, a smaller 5.25 inch drive ($k_2^B = 0$) with 10 MB capacity ($k_1^B = 0.000934$) costing $c_B = \$1910$. Corollary 1 suggests the best customers continue to buy the incumbent's old 8 inch drives. In fact, sales quantity is unchanged ($q_N = 150{,}000$). The entrant opens up a new market segment (desktop users) of equivalent volume ($q_B = 150{,}000$). The incumbent reduces price a bit (by 4.4 %, to $p_N = \$3010$), and its profit is reduced, but not decimated ($\pi_N = \$31.5$ million).

What disk drive incumbents apparently failed to recognize (and what we do not model explicitly in this paper), is that over time, the capacity of the new, smaller disk drive increased faster than the customers' appetites for capacity. In our model, this would cause the reservation price curve for the entrant's new product to shift upward, relative to the incumbent's old product. This progressive shift would allow the entrant's new product to gradually steal the incumbent's low-end customers (in our example, customers of type θ just less than 150,000). But, because these are its worst customers, the incumbent may still be lulled into a false sense of security until it is too late to react. As Bower and Christensen (1995, p. 44) caution, "Managers must beware of ignoring products that don't initially meet the needs of their mainstream customers."

This disk drive example shows that two-dimensional product differentiation, where the strength of customer preferences are negatively correlated, represents another special case of our model. There are other products that seem to exhibit similar characteristics. For example, consider automobiles, and the *strength* of customer preferences along the dimensions of fuel economy and acceleration. A consumer who highly values fuel economy wants a car with good acceleration, but may not be willing to pay as much for the acceleration feature as a sports car aficionado. Conversely, the sports car buff would like to get good gas mileage, but might place less value on this feature than the economy-minded individual. (Clearly, automobiles also possess numerous other dimensions of quality. Thus, we simply use this example

inch drive, sales volumes are 150,000 units per year for each size drive—These volumes are representative of industry sales in late 1981 as suggested by his Exhibit 6.2. More specifically, he shows more 8-inch drives were sold in 1981 (177,000 8-inch versus 52,000 5.25-inch), while more 5.25-inch drives were sold in 1982 (146,000 8-inch versus 218,000 5.25-inch). Costs are NOT taken from his data—These are simply set to yield the price and volume outcomes as given herein. Our model ignores many factors, such as the fact that the incumbent did not have a true monopoly, and the fact that the entrant's market share was built up over time rather than achieved instantaneously. Numbers should, therefore, not be interpreted as those realized by actual firms.

[3]We leave it to the reader to normalize to $(k_1^N + k_2^N) = 1$ and $1085 + k_1^N \theta_4 = 1$, and confirm the outcomes.

to illustrate a possible negative correlation between preferences for two attributes, rather than to suggest automobiles are associated with linear reservation price curves of the type we require.)

7. Summary and Discussion

An objective of this work has been to investigate the role that the operations function plays in product positioning. To date, product positioning models, notably those of Moorthy (1988), Hauser (1988), and Vandenbosch and Weinberg (1995), have assumed the operations function is generic. That is, all firms incur the same cost for any given quality level. In reality, Ulrich and Pearson (1998) show wide disparities in the production costs of products with comparable design attribute levels. Furthermore, the essence of much of the operations literature is to determine ways in which a firm can enhance its cost position.

Thus, both analytical models, and the empirical evidence, suggest firms can establish a competitive advantage on the basis of cost, in addition to the marketing literature which suggests they can do so by differentiating on dimensions of quality. While this insight is not new—It is often suggested a firm should strictly focus on one or the other, differentiation or cost advantage—Our work highlights the manner in which these pursuits are innately related. That is, the firm has some flexibility in how it achieves product superiority. For example, drastic innovation can be achieved via any number of possible combinations of cost reduction and feature enhancements. For the Operations Manager, it is important to recognize how cost initiatives also impact the product's marketability, pricing, sales volume, and profitability. For the Marketing Manager, it is crucial to understand how the degree of product superiority varies as a function of both product attributes and cost. This suggests that, rather than working independently, integration of the marketing and operations functions (i.e., integration of product innovation with process innovation) has the potential to achieve higher overall product superiority, market share, and profitability.

There has been significant work in the field of operations management pointing to the benefits of concurrent product and process engineering, leading to rapid product development time and product designs that are easier to assemble, or otherwise cheaper to manufacture. See Krishnan, Eppinger, and Whitney (1997), for example. Our model does not specifically address development time or synergistic benefits accruing from simultaneous engineering, but does support the notion that product innovation and process innovation are inseparable. What our model does offer is a way for top-level management to assess the product's potential market shares, prices, and profitability, given a product outcome from a concurrent engineering effort.

In addition to determining the financial impact of a new product, a key insight of our model is to depict two key types of market segmentation that result when a new product is introduced. We label these as high-end encroachment and low-end encroachment. (In the first case, the new product steals the best (high-end) customers, while in the second case the new product sells to lower-end customers with lower reservation prices.) We note some empirical evidence for these two forms. For example, Christensen (1997) characterizes new products as representing either *sustaining technology* or *disruptive technology*. It would appear likely that sustaining technology would result in high-end encroachment, because sustaining technologies improve product performance along the dimensions valued most highly by the old product's key customers. Disruptive technology is suggestive of low-end encroachment, because with disruptive technologies, performance in the mainstream market is deficient but the product has other features that appeal to fringe customers.

The significance of our two different forms of encroachment is that they may be viewed quite differently within the firm. With the high-end version, an incumbent will be particularly wary of the entrant's threat of stealing the best customers. An incumbent firm might be well served by heeding the admonishment to "listen to its customers," to find the most effective ways to improve product quality and thereby thwart an entrant's potential investment. For example, Intel has largely been successful in thwarting entrants by continually upgrading the speed of its high-end microprocessor while simultaneously reducing cost (and price) for any given performance level. With the low-end form of encroachment, an incumbent firm may be more susceptible to being blindsided by an entrant, as happened in the disk drive industry.

A limitation of our model is that it does not address the dynamic nature of encroachment. That is, our static model does not address the fact that a new product is apt to evolve (improve) over time, altering the reservation price curves. In addition to changes in reservation prices, learning curve theory suggests cost, and therefore price, changes over time. Thus, the operations function can play a large role in this dynamic process by achieving continual cost reduction, that is, by influencing the learning rate.

The dynamic process translates into a sequential customer adoption process, whereby customer awareness (possibly through advertising), knowledge, and trials may precede the customer purchase decision. Furthermore, while we treat the purchase time frame as a single period, in reality there may be multiple buying phases starting with early adopters and ending with laggards (see, for example, Chatterjee and Eliashberg (1990) for a model of the diffusion process). Additionally, we have not addressed the issue of entry deterrence. These are all issues that would further delineate the market outcome but would require a deeper level of analysis than our simple model provides. Another timing issue that our model fails to address is how a firm may trade off lesser product performance or differentiation in order to achieve a quicker time-to-market. See Cohen, Eliashberg, and Ho (1996).

Thus, our model represents a relatively coarse approach as compared to an actual marketing environment. At the same time, the model appears useful in generating some results that might otherwise be difficult or costly to obtain empirically, such as the predicted relationship between profitability and market share. While managers have sometimes been accused of pursuing market share at the expense of profits, the implication of our results is that these can be parallel pursuits. Our model does not suggest that current profits should be reduced to increase market share. Rather, it says that a firm that strives for profit maximization in its new product development projects will find that a high market share ratio accompanies a high profit share ratio. An outsider more readily observes market share (particularly on a product-by-product basis), which our results suggest may simply be a surrogate for the more dramatic impact that attaining such market share has on the firm's underlying profitability. In other words, our model suggests that the value of innovations that would lead to an increased relative market share are apt to lead to even better increases in relative profits. For example, Jack Welsh, the transforming CEO of GE, stipulated that GE should be number one or number two in every market the firm participated in. Otherwise, GE exited from that market (Tichy and Sherman, 1993). Such a goal appears consistent with the modeling results developed herein.

A limitation of our work to date is that we have not used the model to solve explicitly for the optimal product offering(s) and production processes of a company. Rather, we take the product offerings and cost structures as given and examine the effect on market segmentation, market share and profits. Thus, our current analysis represents only an incremental step toward a more in-depth look at some other aspects of operations, product competition, strategy, and positioning, but at the same time offers some insights into market behavior and represents a modeling tool that might help facilitate future research in these areas.

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Appendix I (Summary of Notation and Terms)

c_B, c_N = unit costs (c) of Products B and N, respectively (constant over volume).

Constrained monopoly: only one firm realizes strictly positive sales, but the firm is constrained to charging less than the monopoly price because of the presence of a competitor's product.

d = disk drive diameter in inches.

D = the degree of product/process innovation (D is a dummy parameter for D_N and D_B).

D_B = degree of innovation for Product B relative to Product N, $D_B = (\nu_B - c_B)/[k\,(1 - c_N)]$.

D_N = degree of innovation for Product N relative to Product B, $D_N = (1 - c_N)/(\nu_B - c_B)$.

Differentiated duopoly: one firm sells one product, and a 2$^{\text{nd}}$ firm sells a differentiated product.

Joint monopoly: a market where only one firm jointly sells multiple products.

k_i^B, k_i^N = the rate of decline in the part-worth for Product B and Product N, respectively, along Dimension i, as customer type increases.

k = ratio of the slope of the reservation price curve for Product B to that for Product N.

m = disk drive capacity in megabytes (MB).

Product B = the product with broad (B) appeal (its reservation price curve has the flatter slope).

Product N = the product with niche (N) appeal (its reservation price curve has the steeper slope).

p_B, p_N = prices (p) of Products B, and N, respectively.

π_B, π_N = profits (π) derived from Products B and N, respectively.

q_B, q_N = sales quantity (q) of Product B, and quantity (q) of Product N, respectively.

θ = a parameter that represents a customer's willingness to pay for product quality.

θ^* = the type of customer who is indifferent between buying Product B and Product N.

θ_B = the type of customer who is indifferent between buying Product B and buying nothing.

θ_N = the type of customer who is indifferent between buying Product N and buying nothing.

S, s = the size of the total potential market (before and after rescaling, respectively).

$s_B(\theta)$, $s_N(\theta)$ = surpluses for a customer of type θ for Products B and N, respectively.

$u_B(\theta)$, $u_N(\theta)$ = utility (reservation price) for customer type θ, for Products B and N, respectively.

$u_i^B(\theta)$, $\nu_i^N(\theta)$ = part-worth a customer of type θ attributes to Products B and N along Dimension i.

ν_B = the maximum reservation price for Product B (associated with a customer of type zero).

ν_i^B, ν_i^N = part-worth a customer of type zero attributes to Products B and N along Dimension i.

Appendix II (Proofs)

Proof of Theorem 1. The proof for part (b) is shown: Proofs for parts (a) and (c) follow similarly. A customer of type $\theta = 0$, $\theta = \theta_N$, $\theta = \theta_B$, or $\theta = \theta^*$ is allowed to buy both products, or both buy a product and buy nothing, because such a customer represents an infinitesimal volume.

Given $\theta_N \le \theta_B \le \theta_N/k$. If $\theta \in [0, \theta^*]$, then $s_N(\theta) = \theta_N - \theta \ge \theta_N - (\theta_N - k\,\theta_B)/(1 - k) = k\,(\theta_B - \theta_N)/(1 - k) \ge 0$, and $s_N(\theta) - s_B(\theta) = \theta_N - k\,\theta_B - \theta\,(1 - k) \ge \theta_N - k\,\theta_B - (\theta_N - k\,\theta_B)(1 - k)/(1 - k) = 0$. Therefore, the customer buys Product N. If $\theta \in [\theta^*, \theta_B]$, then $s_B(\theta) = k\,(\theta_B - \theta) \ge k\,(\theta_B - \theta_B) = 0$, and $s_B(\theta) - s_N(\theta) = k\,\theta_B - \theta_N + \theta\,(1 - k) \ge k\,\theta_B - \theta_N\,(\theta_N - k\,\theta_B)(1 - k)/(1 - k) = 0$. Therefore, the customer buys Product B. If $\theta \ge \theta_B$, then $s_N(\theta) = \theta_N - \theta \le \theta_N - \theta_B \le 0$, and $s_B(\theta) = k\,(\theta_B - \theta) \le k\,(\theta_B - \theta_B) = 0$. Therefore, the customer buys nothing.

Proof of Corollary 1. Per Theorem 1, both products are purchased iff $\theta_N \le \theta_B \le \theta_N/k$ (i.e., iff $0 \le \theta^* \le \theta_N \le \theta_B$), in which case the θ for customers who buy Product N is in the interval $[0, \theta^*]$, while the θ associated with customers who buy Product B is in the interval $[\theta^*, \theta_B]$.

Proof of Theorem 2. There are three possible equilibria: (1) Both firms sell positive quantities; (2) Only Firm N sells a positive quantity; and (3) Only Firm B sells a positive quantity. We establish below the region for each equilibrium.

Both Firms Sell Positive Quantities. If both firms sell positive quantities, then by Theorem 1, $q_N = \theta^* = [(1 - p_N) - (\nu_B - p_B)]/(1 - k)$, and $q_B = \theta_B - \theta^* = [(\nu_B - p_B) - k\,(1 - p_N)]/[k\,(1 - k)]$. Given Firm B's price, Firm N's optimization problem is as follows.

$$\max_{p_N} \quad \pi_N(p_B) = (p_N - c_N)\,q_N = (p_N - c_N)\,[(1 - p_N) - (\nu_B - p_B)]/(1 - k).$$

Subject to: $q_N \ge 0$ and $q_B \ge 0$.

The objective function is strictly concave: $\partial^2\pi_N/\partial p_N^2 = -2/(1 - k) < 0$, and the constraint functions are concave. Thus, the first order condition gives Firm N's reaction function, under the constraints that both firms sell weakly positive quantities. The first order condition yields:

$$p_N(p_B) = [(1 + c_N) - (\nu_B - p_B)]/2. \tag{5}$$

Likewise, we solve Firm B's optimization problem, leading to Firm B's reaction function providing quantities are nonnegative:

$$p_B(p_N) = [(\nu_B + c_B) - k(1 - p_N)]/2. \tag{6}$$

Simultaneously solving (5) and (6) for $p_B(p_N)$ and $p_N(p_B)$, and plugging the equilibrium prices into the equations for quantities and profits yields:

$$p_N = [2(1 + c_N) - (\nu_B - c_B) - k]/(4 - k), \tag{7}$$

$$q_N = [(2 - k)\,(1 - c_N) - (\nu_B - c_B)]/[(4 - k)\,(1 - k)], \tag{8}$$

$$\pi_N = [(2 - k)\,(1 - c_N) - (\nu_B - c_B)]^2/[(4 - k)^2\,(1 - k)]. \tag{9}$$

$$p_B = [2(\nu_B + c_B) - k(1 - c_N) - k\,\nu_B]/(4 - k) \tag{10}$$

$$q_B = [(2 - k)\,(\nu_B - c_B) - k(1 - c_N)]/[k(4 - k)\,(1 - k)] \tag{11}$$

$$\pi_B = [(2 - k)\,(\nu_B - c_B) - k(1 - c_N)]^2/[k(4 - k)^2\,(1 - k)] \tag{12}$$

The condition $q_N \ge 0$ is satisfied iff $(1 - c_N)/(\nu_B - c_B) \ge 1/(2 - k)$, i.e., iff $(\nu_B - c_B)/[k\,(1 - c_N)] \le (2 - k)/k$. These requirements equate to $D_N \ge 1/(2 - k)$, or alternately, $D_B \le (2 - k)/k$. The condition $q_B \ge 0$ is satisfied iff $(\nu_B - c_B)/[k(1 - c_N)] \ge 1/(2 - k)$, i.e., iff $(1 - c_N)/(\nu_B - c_B) \le (2 - k)/k$. These equate to $D_B \ge 1/(2 - k)$, or alternately, $D_N \le (2 - k)/k$. When these conditions are satisfied, the reaction functions $p_B(p_N)$ and $p_N(p_B)$ yield a dynamically stable tâtonnement process: For any initial starting point in prices, iteration of the firms' price-setting process converges to the prices given by and (5) and (6). See Fudenberg and Tirole (1995), p. 24, for further details.

Thus, both firms selling positive quantities is an equilibrium for the Region $1/(2 - k) \le D_N \le (2 - k)/k$ (i.e., for the Region $1/(2 - k) \le D_B \le (2 - k)/k$), with prices, quantities, and profits as given in (7) through (12). Furthermore, in this region the equilibrium is unique, because we include the possibility that Firm N sells nothing (i.e., we allow for $\theta^* = 0$), and the possibility that Firm B sells nothing (i.e., we allow for $\theta^* = \theta_N$).

Only Firm N Sells a Positive Quantity. We search for an equilibrium where only Firm N sells a positive quantity. The only possibility is that Firm N sets price p_N such that Firm B sells nothing ($q_B = 0$) when pricing at cost ($p_B = c_B$). (Similar to the Bertrand result of price competition, if Firm B priced above cost and sold nothing, Firm B would always be willing to reduce price to achieve positive sales.) Thus, we solve Firm N's optimization problem under the constraint that $q_B = 0$ when $p_B = c_B$.

When only Firm N sells a positive quantity, $\theta^* \geq \theta_N$, by Lemma 1. The requirement $\theta^* \geq \theta_N$ can be written as $[(v_B - p_B) - k\,(1 - p_N)]/[k\,(1 - k)] \leq 0$, or as $(v_B - p_B) - k\,(1 - p_N) \leq 0$. Thus, given Firm B's price $p_B = c_B$, Firm N solves the following optimization problem.

$$\max_{p_N} \quad \pi_N = (p_N - c_N)q_N = (p_N - c_N)\,(1 - p_N).$$

$$\text{Subject to:} \quad q_B = 0.$$

The second partial derivative of the objective function is: $\partial^2\pi_N/\partial p_N^2 = -2 < 0$. Thus, the objective function is strictly concave. The constraint is linear in the decision variable, p_N. Therefore, the unique solution meeting the Karush-Kuhn-Tucker (KKT) conditions is globally optimal.

Case i. If $(1 - c_N)/(v_B - c_B) \leq 2/k$, (i.e., if $D_N \leq 2/k$), then the solution is:

$$p_N = [k - (v_B - c_B)]/k, \tag{13}$$

$$q_N = (v_B - c_B)/k, \tag{14}$$

$$\text{and } \pi_N = [k(1 - c_N) - (v_B - c_B)]\,(v_B - c_B)/k^2. \tag{15}$$

In the Region $D_N < 1/k$ we find $\pi_N < 0$, so this solution cannot be an equilibrium (Firm N would rather price at cost, realizing zero profit). In the Region $1/k \leq D_N < (2 - k)/k$ we find the solution results in $\theta^* = \theta_N = \theta_B$, but we found earlier a *unique* solution for this region in which both firms sell positive quantities (note that Firm N's profit in (15) is less than in (9) in this region). Consider the Region $(2 - k)/k \leq D_N \leq 2/k$. The above solution gives $\pi_N \geq 0$. Given Firm B's price $p_B = c_B$ Firm N has no incentive to deviate from the response given by (13) through (15), and given Firm N's price in (13), Firm B has no incentive to deviate from pricing at cost. Thus, this solution must represent an equilibrium, with Firm N's price, quantity, and profit given by (13) through (15), and with Firm B's price $p_B = c_B$ resulting in $\pi_B = q_B = 0$.

Case ii. If $(1 - c_N)/(v_B - p_B) \geq 2/k$, (i.e., if $D_N \geq 2/k$), then the solution is:

$$p_N = (1 + c_N)/2, \tag{16}$$

$$q_N = (1 - c_N)/2, \tag{17}$$

$$\text{and } \pi_N = (1 - c_N)^2/4. \tag{18}$$

Thus, when $D_N \geq 2/k$ an equilibrium in which only Firm N sells a positive quantity is found, with price, quantity, and profit given by (16) through (18). Note that this solution represents Firm N's monopoly price, quantity, and profit, and is independent of Firm B's price $p_B \geq c_B$.

Only Firm B Sells a Positive Quantity. The solution follows that for the case in which only Firm N sells a positive quantity. Once we have found the solutions for the three possible cases, we see that we have perfectly partitioned the possible values of D, so the solution we give for each case is the only solution.

Proof of Corollary 2. The ratios are calculated directly from Theorem 2.

Proof of Theorem 3. Define $\pi \equiv \pi_N + \pi_B$, where π_N and π_B are the firm's profits from selling Product N and Product B, respectively. The firm has three alternatives: (1) Set $q_N > 0$ and $q_B = 0$; (2) Set $q_B > 0$ and $q_N = 0$; or (3) Set $q_N > 0$ and $q_B > 0$. First assume that if the firm chooses 1), setting $q_B = 0$, it sets $\theta^* = \theta_N$. (By Theorem 1, $q_B = 0$ for $\theta^* \geq \theta_N$), and if the firm chooses 2), it sets $\theta^* = 0$. Thus, by Theorem 1, $q_N = \theta^* = [(1 - p_N) - (v_B - p_B)]/(1 - k)$ and $q_B = \theta_B - \theta^* = \theta_B - \theta^* = [(v_B - p_B) - k\,(1 - p_N)]/[k\,(1 - k)]$. Thus, the firm's optimization problem is:

$$\max_{p_N, p_B} \quad \pi = (p_N - c_N)\,q_N + (p_B - c_B)\,q_B = (p_N - c_N)$$
$$[(1 - p_N) - (v_B - p_B)]/(1 - k) + (p_B - c_B)$$
$$[(v_B - p_B) - k(1 - p_N)]/[k(1 - k)].$$

$$\text{Subject to: } q_N \geq 0 \text{ and } q_B \geq 0.$$

The objective function and second derivatives of the constraint functions are concave. Therefore, the following solutions, which meet the Karush-Kuhn-Tucker conditions, are globally optimal:

If $(1 - c_N)/(v_B - c_B) = D_N \geq 1/k$ (i.e., $(v_B - c_B)/[k\,(1 - c_N)] = D_B \leq 1$), then the solution is:

$$p_N = (1 + c_N)/2,$$
$$q_N = (1 - c_N)/2,$$
$$p_B = v_B - k(1 - c_N)/2,$$
$$q_B = 0, \text{ and}$$
$$\pi = (1 - c_N)^2/4.$$

Relaxing the assumption that $\theta^* = \theta_N$ when $q_B = 0$, we find that the same quantities and profits are achieved with $p_B > v_B - k\,(1 - c_N)/2$.

If $(v_B - c_B)/[k\,(1 - c_N)] = D_B \geq 1/k$ (i.e., $(1 - c_N)/(v_B - c_B) = D_N \leq 1$), then the solution is:

$$p_N = 1 - (v_B - c_B)/2,$$
$$q_N = 0,$$
$$p_B = (v_B + c_B)/2,$$
$$q_B = (v_B - c_B)/(2\,k), \text{ and}$$
$$\pi_B = (v_B - c_B)^2/(4\,k).$$

Relaxing the assumption that $\theta^* = 0$ when $q_N = 0$, we find that the same quantities and profits are achieved with $p_N > 1 - (v_B - c_B)/2$.

If $1 \leq (v_B - c_B)/[k\,(1 - c_N)] = D_B \leq 1/k$ (i.e., $1 \leq (1 - c_N)/(v_B - c_B) = D_N \leq 1/k$), then the solution is:

$$p_N = (1 + c_N)/2.$$

$$q_N = [(1 - c_N) - (v_B - c_B)]/[2(1 - k)].$$

$$\pi_N = (1 - c_N)\ [(1 - c_N) - (v_B - c_B)]/[4(1 - k)].$$

$$p_B = (v_B + c_B)/2.$$

$$q_B = [(v_B - c_B) - k(1 - c_N)]/[2\ k(1 - k)].$$

$$\pi_B = (v_B - c_B)\ [(v_B - c_B) - k(1 - c_N)]/[4\ k(1 - k)].$$

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