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WHEN ARE TECHNOLOGIES DISRUPTIVE? A DEMAND-BASED VIEW OF THE EMERGENCE OF COMPETITION

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By identifying the possibility that technologies with inferior *performance can displace established incumbents, the notion of disruptive technologies, pioneered by Christensen (1997), has had a profound effect on the way in which scholars and managers approach technology competition. While the phenomenon of disruptive technologies has been well documented, the underlying theoretical drivers of technology disruption are less well understood. This article identifies the demand conditions that enable disruptive dynamics. By examining how consumers evaluate technology and how this evaluation changes as performance improves, it offers new theoretical insight into the impact of the structure of the demand environment on competitive dynamics. Two new constructs—preference overlap and preference symmetry—are introduced to characterize the relationships among the preferences of different market segments. The article presents a formal model that examines how these relationships lead to the emergence of different competitive regimes. The model is analyzed using computer simulation. The theory and model results hold implications for understanding the dynamics of disruptive technologies and suggest new indicators for assessing disruptive threats.* Copyright © 2002 John Wiley & Sons, Ltd.

From S-curves (Foster, 1986), to technology trajectories (Dosi, 1982) to punctuated equilibria (Tushman and Anderson 1986), the dominant view in technology strategy has been that the displacement of established firms and technologies by new firms and technologies is driven by the superior performance offered by newcomers and established players' difficulties in matching their performance and capabilities. By identifying the possibility that technologies with *inferior* performance can displace established incumbents, the notion of disruptive technologies, pioneered by Christensen (1997), has had a profound effect on the way in which scholars and managers alike approach technology competition and has prompted a reassessment of the ways in which firms approach technological threats and opportunities.

While the phenomenon of disruptive technologies has been well documented, the underlying theoretical drivers of technology disruption are less well understood. Understanding the conditions that give rise to technology disruptions, however, is fundamental to assessing the pervasiveness of the phenomenon and for guiding strategic responses to potentially disruptive threats. Indeed, without a theoretical underpinning with which to answer the question of 'When are technologies disruptive?' it is impossible to make *ex ante* distinctions between disruptive technologies and technologies that are merely inferior.

This article identifies the demand conditions that enable disruptive dynamics. By examining how consumers evaluate technology and how this evaluation changes as performance improves, it offers new theoretical insight into the impact of the structure of the demand environment on competitive

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TECHNOLOGY COMPETITION AND DISRUPTIVE TECHNOLOGIES

Explanations of technology competition outcomes have tended to focus on the supply-side interactions of firms and technologies. At the technology level, outcomes have often been attributed to the exhaustion of the incumbent technology's development trajectory (Foster, 1986; Utterback and Abernathy, 1975) or the entrant's outright superiority. At the firm level, the challenge of managing displacement threats has often been attributed to an unwillingness to cannibalize existing technology investments (Kamien and Schwartz, 1982); organizational inertia (Hannan and Freeman, 1977; Tushman and Romanelli, 1985); and the inability to adopt the necessary skills needed to engage in the new technology (Henderson and Clark, 1990; Leonard-Barton, 1992).

Closer examination of technology competition, however, reveals that technology transitions are not necessarily due to the incumbent technology's inherent limits (Christensen, 1992; Cooper and Schendel, 1976; Henderson, 1995), the new technology's ability to provide superior performance (Christensen, 1997; Levinthal, 1998), or incumbents' inability to master new skills (Bower and Christensen, 1995). While these factors are important, numerous cases of innovative incumbents who did not suffer from these handicaps, yet nonetheless mismanaged the challenge of technological transition (Smith and Cooper, 1988; Smith and Alexander, 1988; Christensen and Rosenbloom, 1995), suggest the need for additional explanations and argue that new insight can be gained by considering the broader environment in which technologies compete (Afuah and Bahram, 1995; Afuah, 2000).

Studies exploring the impact of market demand on development strategies offer a complementary set of explanations that highlight the influence of consumer needs on technology development at the level of technology projects (von Hippel, 1988; Lynn, Morone, and Paulson, 1996), business strategy (Kim and Mauborgne, 1997; Day, 1990; MacMillan and McGrath, 2000) and the broader evolution of technological trajectories (Abernathy and Clark, 1985; Malerba, 1985; Christensen, 1997; Sutton, 1998; Malerba *et al*., 1999; Tripsas, 2001; Adner and Levinthal, 2001).

The most influential expression of a demand-side role in technology competition has been Christensen's examination of disruptive technologies. Disruptive technologies are technologies that introduce a different performance package from mainstream technologies and are inferior to mainstream technologies along the dimensions of performance that are most important to mainstream customers. As such, in their early development they only serve niche segments that value their nonstandard performance attributes. Subsequently, further development raises the disruptive technology's performance on the focal mainstream attributes to a level sufficient to satisfy mainstream customers. While improved, the performance of the disruptive technology remains inferior to the performance offered by the established mainstream technology, which itself is improving as well. Technology disruption occurs when, despite its inferior performance on focal attributes, the new technology displaces the mainstream technology from the mainstream market. Christensen plots the performance-provided and performance-demanded trajectories for different technologies and market segments, and shows that technology disruptions occur when these trajectories intersect. He documents these dynamics in numerous contexts, including hard disk drives, earthmoving equipment, retail stores and motor controls (Christensen, 1997).[1]

[1] Christensen's most prominent illustration of disruptive technologies draws on research in the hard disk drive industry. Accordingly, the hard disk drive example is used to illustrate the arguments made in this paper. Christensen observed that new generations of disk drive technology were first adopted in niche markets which valued the new functionalities they offered. For example, 3.5-inch hard disk drive technology found an early home among notebook computer users who appreciated its reduced weight, size, and power consumption. With further (sustaining) development, 3.5-inch hard drives then went on to disrupt the desktop market, replacing the incumbent 5.25-inch technology. Thus, 3.5-inch hard disk drives displaced 5.25-inch

The dynamics of disruptive technologies are thus characterized by three aspects: incumbent technologies that are displaced from the mainstream market by technologies that underperform them on the performance dimensions that are most important to mainstream consumers; mainstream consumers who shift their purchases to products based in the invading technology, even though those products offer inferior performance on key performance dimensions; and incumbent firms that do not react to disruptive technologies in a timely manner.

Christensen explains these dynamics as resulting from the interaction of resource dependence (Pfeffer and Salancik, 1978) and performance oversupply. He argues that the resource dependence of incumbents on their most demanding customers guides investments towards enhancing focal mainstream performance features. Because the incumbent technology offers superior performance on these dimensions, incumbent firms' investments are directed towards extending the existing technology, rather than the (potentially) disruptive technological opportunity. Incumbents have an additional incentive to ignore disruptive technologies because, with their lower performance, they appeal to the low-end, low-profit portion of the mainstream market. In contrast, entrant firms, whose decisions are not constrained by an existing customer base and whose technology offers inferior performance on the focal mainstream dimensions, are forced to identify consumers who value the new features offered by the new technology and support its further development.

Christensen introduces the idea of 'performance oversupply' to explain the mainstream consumers' decision to adopt the disruptive technology in the face of superior incumbent technology. The principle of performance oversupply states that once consumers' requirements for a specific functional attribute are met, evaluation shifts to place greater emphasis on attributes that were initially considered secondary or tertiary. By this logic, when the capacity provided by 5.25-inch hard disk drives exceeded the requirements of desktop consumers, these consumers began to place greater weight on attributes such as size and weight in their purchasing decision and thus chose 3.5-inch hard drives despite their lower capacity and higher cost per megabyte.

This explanation of the drivers of technology disruption leaves several issues unresolved. Clearly the different functional package offered by the disruptive technology plays a role in its adoption in the initial niche market. However, the newfound prominence of previously marginal attributes seems an incomplete explanation for adoption in the mainstream market—why would desktop users care about weight or size of internal hard disk drives? Similarly, much has been made of the performance and price/performance disadvantages of disruptive technologies relative to their mainstream rivals, but the explicit roles of price and performance in driving disruptions have remained underexplored. Finally, while the prominence of the performance-provided–performance-demanded relationship highlights the critical role of the demand environment in shaping disruptive competition, the demand-side factors that drive the emergence of competition remain largely unstudied. For both researchers and managers, resolving these issues is a necessary condition for defining the boundaries of disruptive technologies.

A DEMAND-BASED VIEW OF TECHNOLOGY COMPETITION

This article develops a demand-based view of technology competition that resolves these open questions surrounding disruptive technologies by formally modeling the role of the demand environment in shaping competitive dynamics. The structure of demand is characterized by two elements of the relationship between market segment preferences: *preference overlap* and *preference symmetry*. Preference overlap refers to the extent to which development activity that is valued in one segment is also valued in another segment. Preference symmetry refers to the symmetry of this overlap, the relative size of the functional 'shadows' that segments cast on each other. The article presents a model that examines how technology improvements can blur the boundaries that divide market segment and lead to different competitive environments. It shows that the extent to which demand

drives from the mainstream desktop market, despite offering lower storage capacity, slower data access speeds, and being more costly on a dollar-per-megabyte basis. Further, those firms that dominated the desktop market with 5.25-inch technology did not manage the transition to 3.5-inch technology and were displaced by entrant firms employing the new technology. Note that the context is internal *hard* disk drives, not removable floppy disks, and that compatibility and disk portability (as opposed to computer portability) are not significant concerns for consumers.

heterogeneity is masked depends on consumers' marginal utility from performance improvements, which dictates their willingness to pay for product enhancements, and on the relationship between the functional preferences of the different market segments.

The model is used to examine how preference overlap and preference symmetry interact to affect the emergence of competition. Controlling for supply-side asymmetries such as initial resource endowments and technological potential, the model examines the nature of three distinct competitive regimes that arise under varying configurations of demand: competitive *isolation*, in which technologies do not interact throughout the course of their evolution; competitive *convergence,* in which technologies evolve to compete head-on for the same consumer groups; and competitive *disruption*, in which one technology cedes dominance of its home market to its rival.

As technology development progresses, consumers' performance requirements are met, and then exceeded, by their home technology. As performance continues to surpass consumers' requirements, consumers' willingness to pay for improvements decreases, opening the door for lower-priced, lower-performance (disruptive) offers to capture these consumers. As the overlap between market segments' preferences increases, firms have greater incentives to enter rivals' markets. When preference overlap is asymmetric, the firm whose technology casts a larger performance shadow on its rival's market, and whose technology is therefore relevant to a larger number of consumers, has greater incentive to invade, trading price for volume. The invaded firm, confronting a smaller set of potential users, chooses to exploit existing opportunities in the uncontested portion of its market segment rather than engage in price competition with its rival.

The results of the analysis highlight the relationships among consumer preferences and consumers' willingness to pay for performance improvements as key factors that give rise to technology disruptions. The analysis reveals the dynamics by which the underlying heterogeneity in market preferences, which initially acts to separate market segments and attenuate competition, is progressively masked as technology improvements exceed consumer requirements. The results also identify the increasing importance of unit price in determining consumers' choices as technology performance progresses beyond their requirements. This finding offers an alternative to performance oversupply in explaining the consumer adoption of disruptive technologies and points to price trajectories as useful complements to performance trajectories in identifying disruptive threats. These findings are supported by data from the hard disk drive industry.[2]

The remainder of the paper is structured as follows: first, a conceptual characterization of demand and demand structure is presented. This characterization is then used to develop a formal model for examining how demand structure influences competitive interactions. The model is analyzed using computer simulation and the simulation results are presented and interpreted. The paper concludes with a discussion of the results and their implications for understanding disruptive technologies and, more broadly, the evolution of competition.

DEMAND STRUCTURE

To understand the influence of demand structure on the emergence of competition we must characterize the demand environment in which technologies compete. To do this we model the behaviors of consumers as individual decision-makers and as members of market segments. Consumers are characterized by the way they trade off performance on different functional attributes, their willingness to pay for performance improvements, and the minimum performance threshold that a product must reach if it is to be of value to a given consumer. Market segments are composed of consumers with the same performance trade-offs and are identified by value trajectories, which characterize the trade-off. The focus of the analysis is the relationship between market segment's value trajectories and on the emergence of competitive isolation, convergence and disruption.

[2] Adner and Zemsky (2001) develop a formal game theoretic model that builds on the analysis in this paper and generalizes some of its results. They formally characterize the breakdown of competitive isolation and examine the additional effects of asymmetric costs, segment sizes and number of firms using each technology.

Individual consumers: thresholds, utilities and diminishing returns

The notion of thresholds, defined as critical performance levels that must be met for an offering to become relevant to a decision set, is well established in the social sciences (Granovetter, 1978; Varian, 1978; David, 1969; McFadden, 1986; Meyer and Kahn, 1991). We distinguish between two types of thresholds. A consumer's *functional threshold* specifies the minimum level of performance below which a consumer will not accept a product *regardless of its price.* Functional thresholds are determined in part by inherent task requirements and in part by context. Thus, a product that falls below one consumer's functional threshold may well be acceptable to another consumer with a different functional threshold.

As product performance improves beyond the functional threshold, a consumer's relative preferences among the possible functional attributes impact the benefit she derives from the product. Functional benefit is thus a function of both the product's objective performance on each functional attribute (e.g., speed, capacity, reliability) and the consumer's trade-offs among these attributes.[3] For example, while a vehicle that can carry 50 passengers with a maximum speed of 30 miles per hour may satisfy the functional thresholds of both a private driver and a public transportation driver, the latter will derive greater functional benefit from the offer. Thus, functional requirements indicate initial thresholds while relative preferences dictate consumers' evaluation of performance improvement. In this regard, Christensen's trajectories of performance demanded by different market segments can be interpreted as plots of average segment functional thresholds.

Net utility thresholds incorporate price into the consumer's decision function, specifying the highest price a consumer will pay for a product that just meets her functional threshold. Here too, we may expect to find heterogeneity among consumers, even those with similar functional preferences. Differences in consumers' willingness to pay may be driven by differential budget constraints. They may also be driven by nonbudgetary considerations; for example, differences in the ability of the customer to exploit the product. Such heterogeneity may stem from the customer's internal resources (Barney, 1986), capabilities (Amit and Schoemaker, 1993) or human capital (Becker, 1962) (e.g., an efficient programmer is able to derive more benefit from a given computer system than can an inefficient programmer). Alternatively, differences in consumers' willingness to pay may stem from the scale at which the buyer can apply the product. A customer who can apply the product toward the production of a good that he can sell to a large downstream customer base will be willing to pay more for the product than a customer with a smaller customer base. Finally, differences in willingness to pay may reflect variation in the availability and presence of a substitute product or service. A consumer who has previously invested in a substitute good will benefit from the new product only to the extent of the product's relative performance improvement over the existing substitute. A similar consumer, not in possession of a substitute, will value the product on the basis of the absolute benefit it provides.

While consumers have a minimum threshold for acceptable performance, there is no analogous boundary that specifies a maximum limit to the functional performance that a consumer would be willing to accept.[4] At the same time, consumers face decreasing marginal utility from increases in functionality beyond their requirements (Meyer and Johnson, 1995). Correspondingly, it is reasonable to assume that consumers show a positive, but decreasing, willingness to pay for improvements beyond their requirements. Even if consumers place little value on performance differences at sufficiently high absolute levels of functionality they will still, all else being equal, choose the more advanced product.[5]

[3] This conceptualization follows a long tradition of work in marketing, decision science, and economics (Griliches, 1961; Lancaster, 1979; Green and Wind, 1973; Trajtenberg, 1990) that suggests that consumers have relative preferences for product characteristics and that consumer choice can be usefully conceived as the maximization of utility measured in terms of the functional characteristics that are embodied in their product choices. The treatment of preferences for goods as being derived from preferences for collections of characteristics lies at the heart of established techniques such as hedonic analysis, conjoint analysis, and multidimensional logit models of brand choice.

[4] For the purposes of this paper increased functional performance is treated as a purely a positive feature.

[5] Using a related model to study patterns of technology innovation, Adner and Levinthal (2001) find that competing firms may continue to enhance product performance beyond consumers' needs, even when such enhancements have little effect on consumers' willingness to pay, as a form of nonprice differentiation.

Market segments: Value trajectories and the structure of demand

Market segments are composed of consumers with similar functional preferences. Segment members may have heterogeneous functional and net utility thresholds. As a useful shorthand we define segments' *value trajectories* as characterizing the member consumers' relative preferences for functional attributes. The relationship between value trajectories maps the structure of demand. The overlap between value trajectories and the symmetry of this overlap indicates the differential market incentives firms face in choosing their innovation activities, which in turn drive the emergence and evolution of competition. These relationships are developed formally in the next section.

As illustrated in Figure 1, the value trajectory identifies the direction of propagation of a market segment's indifference curves as they progress toward higher utility levels.[6] Consumers' evaluation of products' functional performance is determined according to the products' projection onto the value trajectory—the farther out on the value trajectory the projection, the greater the product's utility to the consumer.

Consider the following simplified example from the market for information storage products. Figure 2 shows hypothetical value trajectories for consumers in the market for desktop personal computers (PCs), who value storage capacity much more than portability; consumers in the market for personal digital assistants (PDAs), who value portability much more than storage capacity; and consumers in the market for notebook computers (NCs), who value capacity and portability in equal measure.

The *preference overlap* between these segments is the degree of similarity between their functional preferences, which is graphically reflected in the difference between their trajectories. The greater the preference overlap, the closer the value trajectories, and the greater the segments' agreement on the level of product performance. As illustrated in Figure 2(a), whereas the PC group derives a utility level of 3 from product A and a utility level of 1.4 from product B, the PDA group derives a utility level of 1.4 from product A and 3 from product B. As preference overlap increases, as illustrated in Figure 2(b) for the PC and NC groups, these evaluations converge. Here, the PC group's derived utilities of 3 and 2.7 from products A and C, respectively, are in greater agreement with the utilities of 1.6 and 3 derived by the NC group. Preference overlap is thus a measure of the extent to which one market segment's satisfaction with a given product's functionality is indicative of the satisfaction of another group—the performance shadow cast on a segment's value trajectory by progress along its counterpart's trajectory. When individual firms initially pursue different market segments, the segments' preference overlap is an indicator

[6] The value trajectory is the gradient of the Cobb-Douglas utility curve. It is thus the vector that minimizes the level of total functional attainment required to attain a specified utility level. In Lancastrian terms it is defined by the vector which minimizes the characteristic resources required to attain a given utility level; that is, the vector along which the compensating function is equal to unity (Lancaster, 1979, 1991).

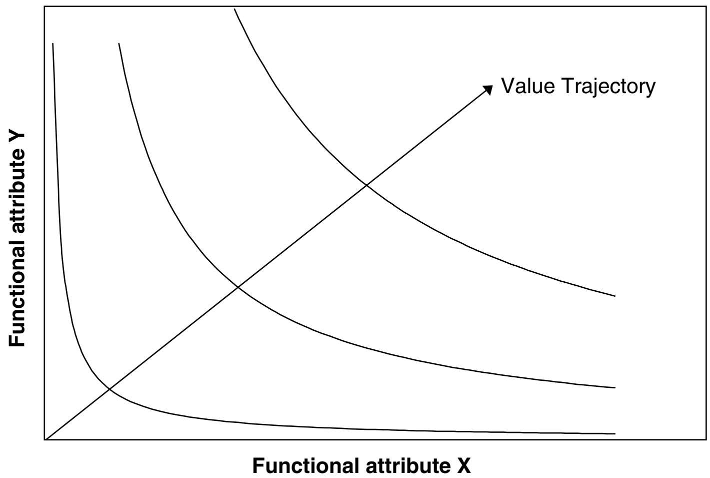

Figure 1. Indifference curves and a value trajectory

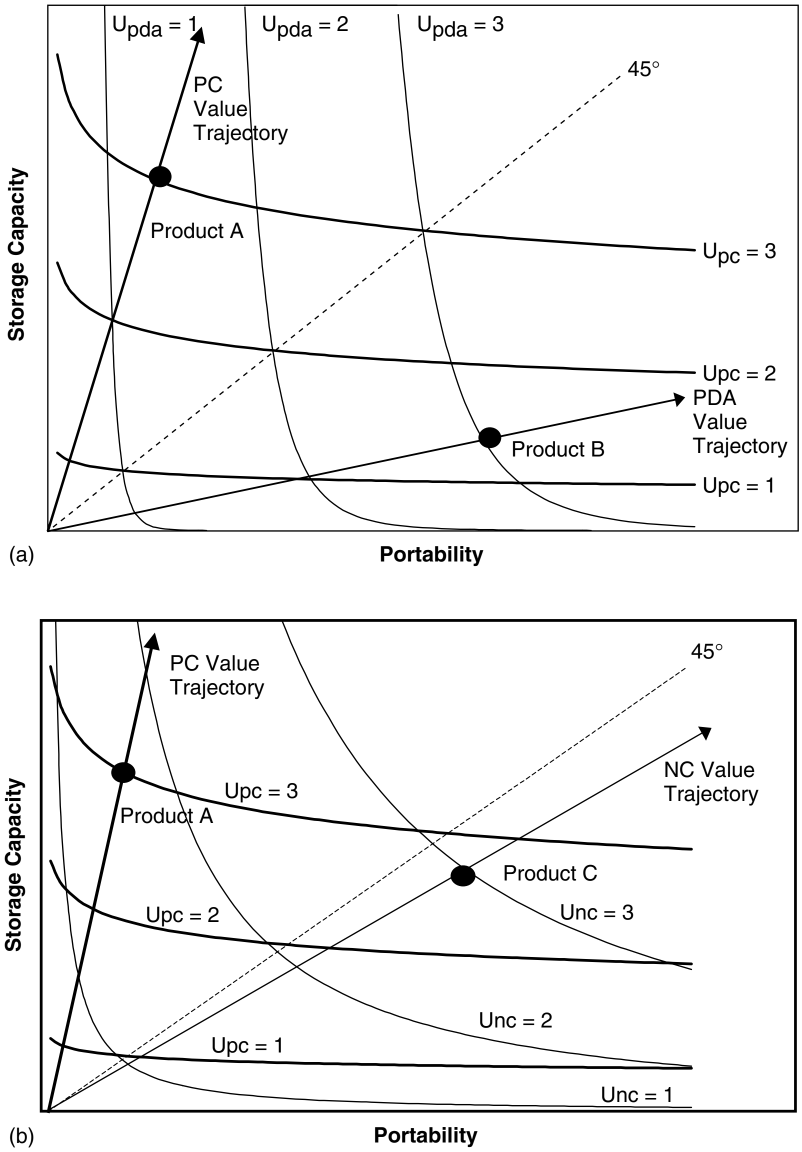

Figure 2. (a) Small, symmetric preferences overlap. (b) Large, asymmetric preference overlap

of the ease with which the firms can invade other market niches.

While the magnitude of preferences overlap speaks to the absolute degree of preference similarity, *preference symmetry* refers to the relative value each segment places on performance improvements along another segment's value trajectory. When preference overlap is symmetric the utility which one group derives from a given level of performance along the others' trajectory is the same for both groups. In the case of the PC and PDA groups, each derives a functional utility level of 3 when the other drives a level of 1.4. When preferences are not symmetric, a product positioned at a given distance along one segment's value trajectory provides a different level of utility to members of the other segments than a product positioned at the same distance along the other segment's value trajectory provides to members of the first segment. In the case of the PC and NC groups, for a utility level of 3 along its counterpart's value trajectory, the PC group will derive a utility of 2.7, while for a utility level of 3 along the PC group's value trajectory the NC group derives a utility of only 1.6. For firms initially pursuing different market segments, the symmetry of preference overlap plays a critical role in structuring their differential incentives for pursuing other segments.

Conceptualizing demand according to consumers' requirements and preferences suggests a demand landscape that coevolves with technology development: as consumers' requirements are exceeded, they derive positive but decreasing marginal utility from further performance improvements. This satisfaction leads to the need for greater and greater performance increases to support a given increase in utility, which is reflected in a decreasing willingness to pay for a given level of performance improvement. Stated differently, as performance exceeds requirements, price increases in importance. As developed below, these changes in consumers' valuation of performance improvements lead to changes in firms' innovation incentives, which in turn affect consumers' decisions in future periods.

MODEL STRUCTURE

The model follows in the Lancastrian tradition of conceptualizing the market space along attribute dimensions. It extends previous applications of characteristics demand models by examining how the relationship between the value trajectories of discrete market segments affects firms' development choices throughout a technology's evolution and how these factors affect the emergence of competitive dynamics. The model is used to examine the behavior of two firms pursuing independent technology initiatives in a market with two consumer segments.

The model structure has two basic components: a characterization of consumers and consumer preferences, which comprises the market, and a mechanism by which products move through this market space. The market space is defined by two functional dimensions and by a price dimension.[7] In every period, single-product firms make development decisions that affect the location of their product technology in this space; consumers, in turn, respond to the product offerings by purchasing either a unit quantity of the product or making no purchase at all.

[7] The model is presented using two functional dimensions, but can be extended in a straightforward manner to incorporate higher-dimensional spaces.

The model assumes repeat purchasing behavior such that the entire population of consumers considers making a single unit purchase in every period. Consumer preferences are stable over time, but, consumer purchase decisions may vary as product offerings change over time. The model assumes that there are no switching costs, consumption externalities, capacity constraints, economies of scale, or price discrimination. Consumers are assumed to have a one period decision horizon and to be well informed, with perfect information about product performance.[8] Given a choice among a set of acceptable products, a consumer will select the product that meets her thresholds, improves her utility over her previous purchase, and maximizes her utility in the present period. In every period the entire population of consumers is exposed to the available products and each consumer selects her own best choice.

Consumer choice

In the model individual consumers are characterized by their threshold requirements and their relative preferences for improvements beyond these requirements. Each individual, i, has a net utility threshold, U_{i0}, which a product must meet to be considered for purchase. An individual derives utility from a given product offering according to the functional benefit she derives from the product and from its price. Functional benefit is determined by the functionality of the product in excess of the consumer's functional threshold requirements, F_{i0}, and by the consumer's relative preference for each

[8] The model makes the simplifying assumption that consumers are perfectly informed regarding product performance. Because the interest is in the qualitative pattern of behavior, consumer uncertainty would be a relevant factor if it were to affect firms' development decisions in a nonsystematic way. Given, *ex ante*, no compelling reason to bias consumers' assessment of product performance in either the positive or negative direction, the error in the assessment would have to be modeled as a symmetric distribution around the true value. If consumers are assumed to be risk neutral, and the error random, the expected actions of the populations would mirror the fully informed case. If consumers are assumed to be uniformly risk averse (risk seeking), their functional requirements would shift up (down) to compensate for the uncertainty. Such a shift, while affecting the absolute values associated with the observed outcomes, would not affect the qualitative nature of the results. The more complex case of heterogeneous risk preferences is beyond the scope of the current discussion.

dimension of functional performance, γ.[9] The consumer's trade-off between functional benefit and price is α.

The market space is defined by two functional dimensions, X and Y. B_{ij} is the functional benefit derived by consumer, i, with functional threshold requirements of F_{ix} and F_{iy}, from product j, which offers functionality $\mathbf{F}_j$, with components F_{jx} and F_{jy}.

$$B_{ij} = B_i(\mathbf{F}_j) = \begin{cases} (F_{jX} - F_{iX})^{\gamma}(F_{jY} - F_{iY})^{1-\gamma} \\ \quad +1 \text{ if } (F_{jX} - F_{iX}), \\ \quad (F_{jY} - F_{iY}) \geq 1 \\ 0 \text{ otherwise} \end{cases} \tag{1}$$

where $0 < \gamma < 1$.

The utility, U_{ij}, that consumer i derives from product j is specified as a Cobb-Douglas utility function which trades off product price and functionality[10]:

$$U_{ij} = U_i(\mathbf{F_j}, P_j) = (B_{ij})^{\alpha}(1/P_j)^{1-\alpha} \tag{2}$$

where $0 < \alpha < 1$.

Consumers will reject any product that does not meet both their functional and net utility thresholds, requiring both $B_{ij} \geq 1$, and $U_{ij} \geq U_{i0}$. Thus P_{i0}, the price a consumer will be willing to pay for a product that just meets his functional threshold, ($B_{ij} = 1$), is:

$$P_{i0} = (U_{i0})^{1/(\alpha-1)} \tag{3}$$

P_{ij}, the maximum price a consumer would be willing to pay for a product that exceeds his functionality requirements, is thus:

$$P_{ij} = P_{i0}(B_{ij})^{\alpha/(1-\alpha)} \tag{4}$$

As discussed above, consumers value functionality improvements beyond their threshold requirements, $\partial U_{ij}/\partial B_{ij} > 0$, but at a decreasing rate, $\partial^2 U_{ij}/\partial B_{ij}^2 < 0$. This valuation is reflected in consumers' decreasing willingness to pay for improvements, $(\partial P_{ij}/\partial B_{ij} > 0,\ \partial^2 P_{ij}/\partial B_{ij}^2 < 0)$, when $\alpha < 0.5$.

Demand structure

In the model the essential aspects of demand structure derive from the relationship between consumers' relative functional preferences, γ. Consumers belong to one of two market segments. All members of a market segment, m, have the same relative functional preferences γ_m. The value of γ_m specifies a market segment's value trajectory. Graphically, for two functional dimensions, the degree measure of the value trajectory is 90° $(1 - \gamma)$.

For two market segments A and B, whose derived utility from two functional attributes X and Y is described by:

$$U_A = (F_X)^{\gamma_A}(F_Y)^{1-\gamma_A} \tag{5a}$$

$$U_B = (F_X)^{\gamma_B}(F_Y)^{1-\gamma_B} \tag{5b}$$

where $0 \leq \gamma_A, \gamma_B \leq 1$.

Preference overlap is defined as:

$$\text{Preference overlap} = 1 - |\gamma_A - \gamma_B| \tag{6}$$

The greater the preference overlap, the greater the segments' agreement on the rank ordering of alternatives. When preference overlap is zero, the segments' preferences are entirely divergent, so that progress along one segment's value trajectory has no impact on the other segment's assessment of the product's functional benefit. When preference overlap is unity, the value trajectories coincide and the two segments have identical functional preferences, essentially behaving as a single segment.

Preference symmetry, the extent to which one segment's preferences project onto the others' preferences, is defined as:

$$\text{Preference symmetry} = |0.5 - \gamma_A| - |0.5 - \gamma_B| \tag{7}$$

When the preference symmetry measure is zero, preferences are symmetric and unit progress on each segment's value trajectory yields equal functional benefit to consumers in the other segment.[11]

[9] $\mathbf{F}_{i0}$ is a vector which specifies consumer i's minimum functional attainment required on each functional dimension. Graphically, it is the position along an individual's value trajectory that a product must pass to become decision relevant.

[10] Note that $[\log U]/(1-\alpha) = \alpha/(1-\alpha)\log B - \log P$. Hence the model is a monotonic variant on the utility function of standard vertical differentiation models $U = KB - P$ (Tirole, 1988). The current model differs from the standard model in that it incorporates multiple functional dimensions, minimum thresholds for functionality and diminishing returns to functional improvements.

[11] Implicit in this discussion is the assumption that the distance between indifference curves is cardinal, which allows

When the preference symmetry measure is positive (negative), the projection of segment B's value trajectory on segment A's value trajectory is greater (less) than A's is on B's, and a unit advance along B's value trajectory will yield greater functional benefits to consumers in segment A than vice versa.

Technology development

In the model, technology initiatives are characterized by their performance on each functional dimension and by a production cost. Technologies are developed by firms. Firms introduce products to the market on the basis of their technology positions, with the goal of maximizing profits in the current period. Each firm is initially endowed with a technology that has initial functional and cost characteristics. In the course of the simulation, firms develop their technologies in response to the opportunities they perceive in the marketplace. Technology development is locally constrained, and therefore path dependent, but globally unconstrained regarding the absolute limit of technology progress. As described below, in every period firms can engage in product innovation, process innovation, or can choose to forgo the opportunity to innovate. Following the characterization used in previous analytical models (Cohen and Klepper, 1996; Klepper, 1996), the effects of product and process innovations are reflected in changes in product functional performance and in product cost.

Product innovation enhances performance along the functional dimensions by a fixed Euclidean distance in market space, $\mathbf{F}^{\text{prod}}$, and leads to a fixed production cost increase, C^{prod}. In the spirit of an evolutionary approach, $\mathbf{F}^{\text{prod}}$ is relatively small in comparison to the range of functional performance demanded in the market ($\max \mathbf{F}_{i0} - \min \mathbf{F}_{i0}$), such that numerous product development attempts are required if a firm is to satisfy the functional requirements of all consumers in the market. As discussed below, the allocation of effort along functional dimensions, ΔF_x and ΔF_y, is determined according to a local search of the market opportunities presented to the firm.

A product innovation affects product j as:

$$\mathbf{F}_{j,t+1} = (F_{jX,t} + \Delta F_X), (F_{jY,t} + \Delta F_Y) \qquad (8a)$$

where $[(\Delta F_X)^2 + (\Delta F_Y)^2]^{1/2} = |\mathbf{F}^{\text{prod}}|$

$$C_{j,t+1} = C_{j,t} + C^{\text{prod}} \qquad (8b)$$

The choice of relative allocation of improvement determines the technology's development trajectory. While this trajectory can be altered in every period, the firm is charged a development cost against profits that is proportional to the shift in trajectory.

Process innovation leaves product functionality unchanged while lowering the cost of production by a constant percentage, Δ_c. Thus, a process innovation affects product j as:

$$\mathbf{F}_{j,t+1} = \mathbf{F}_{j,t} \qquad (9a)$$

$$C_{j,t+1} = C_{j,t}(1 - \Delta_c) \qquad (9b)$$

Firms can pursue one innovation per period. A firm can pursue either innovation mode in any period and for as many periods as desired. Further, there is no uncertainty as to the success of an innovation attempt.[12] Firms are charged an innovation cost, I, in every period in which they choose to innovate.

In the model, firms choose innovative activity on the basis of local, profit-maximizing search. Firms search their local market environments to predict consumer reaction to changes that are attainable through a single product or process innovation. The model assumes that firms are fully informed regarding consumers' responses to pricing and that firms can, given their product's performance and production costs, determine the price point which will yield greatest period profit. Firms are unable to evaluate potential consumer demand for changes

for comparisons regarding positions and advances along valuation trajectories. While unconventional in classical demand theory, Lancaster speaks of the desirability of being able to make quantitative utility comparisons across goods (Lancaster, 1991: 158–159). Because his closed-form models do not allow for the simultaneous consideration of final utilities for multiple consumers, he opts for a 'second best' approach which proxy's resource content for derived utility. The simulation methodology used to examine the current model allows, in the spirit of Lancaster's stated intent, for the explicit consideration of cardinal utilities, and such utilities are therefore used.

[12] Clearly, eliminating uncertainty regarding innovative outcomes is a strong simplification. However, as was the case with consumer uncertainty, because there is no justification, *ex ante*, to bias expectations, the addition of an error term would not affect the qualitative behaviors that are of concern here.

that result beyond a single development action.[13] Firms are unable to predict their rival's development activity. Firms become aware of their rival's activities through their reflection in consumer purchasing decisions—consumers who were expected to purchase but did not. Firms' expectations of market response is thus determined by their product's functional state, the magnitude of innovation that can be executed in a single period, the firm's pricing decision, and the product offers of the previous period.[14]

In the evaluation of potential product innovation, the firm must determine the allocation of its development efforts among the functional dimensions and determine a price point at which to offer the product to the market. The firm has a profit expectation for each possible action that is determined by its production costs, development costs, and predicted market feedback. Similarly, the firm has a profit expectation for potential process innovation by predicting market response to different price points given its reduced production costs. The firm commits to the innovation activity that is expected to yield the highest profits for the ensuing period. If the expected profits from innovation are not greater than the realized profits from the previous period, the firm will forgo innovation for the period.

Model analysis

The model is used to examine the behavior of two firms pursuing independent technology initiatives in a market with two consumer segments. The analysis explores how changing the preference overlap and preference symmetry of the segment's value trajectories affects the emergence and evolution of competition. The model is analyzed using a computer simulation programmed in Pascal.

The first procedures of the simulation initialize the population of consumers and the initial characteristics of the product technologies. The consumer population is initialized by specifying each consumer's minimum functionality and utility requirements. The market segments are specified by their value trajectories. The range of consumers' minimum functional thresholds is such that approximately 20 product innovation attempts are necessary to span the distance between the minimum requirements of the least and most demanding customer in the market. Consumers are randomly drawn from a uniform distribution along this range. Consumer preferences and requirements remain constant throughout the simulation, but buying behavior changes as firms' development activities change the product technologies' characteristics. Each firm's technology is initially positioned along the value trajectory of one of the market segments. The specification of value trajectories and initial product technologies is discussed in the results section.

After initialization, the following sequence of events is repeated until the market dynamics reach a steady state.[15] First, each firm engages in local search to determine the profit expectations for each possible development action. Second, the firms commit to the activity that will yield the highest expected profit. Third, every consumer independently evaluates the available product offerings and decides on purchase as above. Finally, market outcomes are tallied and firms realize their actual market pay-offs. In the representative results discussed below the market space is seeded with 250 consumers who are evenly distributed between two market segments. Individual consumers' functional requirements, $|\mathbf{F}_{i0}|$, are uniformly distributed along the range from 5 to 25. Each firm's technology is initially seeded along a segment's value trajectory with $|\mathbf{F}_j|$ set at 7 and initial production cost 1.7. These settings provide for an initial isolation between the technologies. In the absence of some distance between their initial positions the firms face identical market landscapes and therefore always engage in convergent competition.

For all presented results, $\alpha = 0.2$, $F^{\text{prod}} = 1$, $C^{\text{prod}} = 0.1$, $\Delta_c = 0.05$. While changing parameter values affects the absolute magnitudes and rates of

[13] To the extent that firms engage in additional market research, these efforts would be reflected in a search radius that would extend beyond their immediate development opportunities. Such market research would affect behavior when the relative preferences of more distant consumers differ from the preferences of their local counterparts.

[14] This model of local, profit-maximizing search speaks to investments that are driven by immediate market opportunities rather than those driven by visionary, long-term goals. Thus, it does not speak to activities with very long-term investment horizons such as pharmaceutical R&D or visionary technology bets made without expectation of any short-term return.

[15] Steady state is defined as having been reached when combined sales for both firms remain unchanged for 15 consecutive periods.

behaviors, the qualitative patterns of competition are robust. Similarly, the qualitative results are robust with regard to the stochastic seeding of the consumer population. The results are presented in terms of the development activities of two firms, Firm 1 and Firm 2, that act in a market space with two consumer segments, segment *A* and segment *B*. At the start of the simulation, Firm 1's technology position is aligned with segment *A*'s value trajectory and Firm 2's technology position is aligned with segment *B*'s value trajectory.

RESULTS

The simulation explores how the structure of demand influences the emergence and extent of competition over consumer segments in the market. On the supply side we are interested in the technologies' functional development and pricing decisions, while on the demand side we are interested in the degree of firms' penetration into market segments, in terms of both satisfaction of consumers' requirements and consumers' actual purchasing decisions.

Figure 3 presents a stylized summary of the relationships between preference overlap, preference symmetry and the competitive regimes to which they lead. Holding one value trajectory fixed, the figure maps the competitive regimes that arise as a second value trajectory is varied.[16] Three qualitatively distinct dynamics emerge during the course of the analysis. Under demand conditions of low preference overlap, the development dynamics lead to *competitive isolation*, a pure partitioning of the market between the technologies, such that each focuses exclusively on its own segment. As preference overlap increases, isolation breaks down and the development dynamics lead to the emergence of two distinct classes of competition. When segment preferences are symmetric we observe *competitive convergence*, in which each technology's development is directed at expanding its appeal not only in its own home market but in its rival's as well. When segment preferences are asymmetric we observe *competitive disruption*, in which one firm maintains dominance of its home market while displacing its rival from the rival's market.

As a technology's performance advances, it surpasses the requirements of a growing number of

[16] The objective of the model is to provide a qualitative representation of the competitive patterns of interest, rather than a quantitative replication of particular settings. In this spirit, the results are presented in terms of three representative demand configurations and the dynamics. Because the precise (numerical) location of the boundaries between the regimes is dependent on specific parameter values as well as the random seeding of the consumer population it is not a focus of this analysis. The interested reader is referred to Adner and Zemsky (2001), which presents closed-form expressions for the breakdown of isolation.

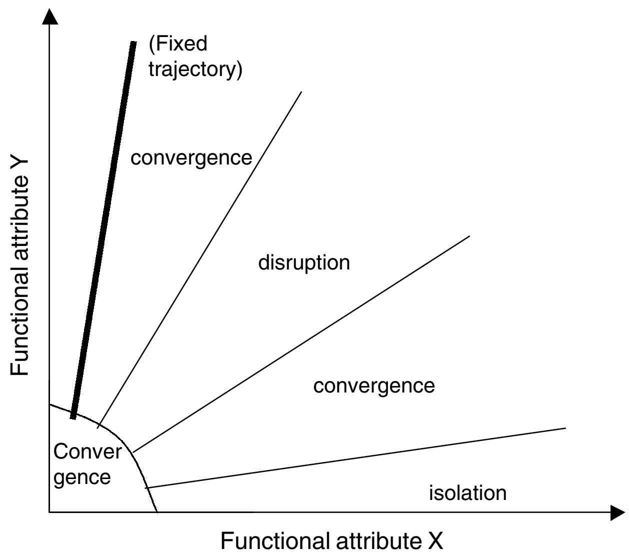

Figure 3. Preference relationships and competitive regimes: holding the preferences of one segment fixed (value trajectory shown in bold), different competitive regimes arise as the relative preferences of the second segment are varied

consumers in the home market and, with sufficient preference overlap, it begins to satisfy and surpass the requirements of consumers in the foreign market. When preferences are asymmetric, the firm whose home market casts the larger functional shadow faces greater marginal incentives to pursue consumers outside its home market because its offer appeals to a larger number of consumers. As the invading firm pursues consumers at the low end of its rival's segment with low-priced offerings, the invaded firm can either defend its position at the low end through price reductions or focus on its own high-end consumers with higher price and performance offers. From the invaded segment's perspective the appeal of the invading technology, which offers neither higher performance nor higher price/performance value, is due to its lower unit price.

Demand structure and competitive isolation

Competitive isolation, in which each technology is sold only in its home market, is characteristic when the preference overlap is small. Figure 4 shows representative simulation results for the low overlap case in which the two market segments have functional preference parameters $\gamma_A = 0.1$ and $\gamma_B = 0.9$. This case characterizes the PDA–desktop segments for hard disk drives in the stylized example above. Initially, technology initiatives satisfy the functional requirements of only their home segment and development proceeds along a path that matches that segment's value trajectory. Because of the wide difference in relative preferences, technology development following one segment's value trajectory does not lead to significant improvement along the other segment's criteria. Firms' development and pricing decisions are thus substantially determined by the requirements of their home segments. As development proceeds, and functional attainment increases, the firms are able to satisfy the functional requirements of the lower end of the foreign market segment. By this point, however, the appeal of pursuing these customers is limited by two factors: (1) its rival offers a higher-functionality product; and (2) to reach these customers, given the functionality of the existing alternative, the firm would need to lower prices well below the level it is able to charge its existing customers. Thus, while consumers in the foreign segment are functionally visible, their price requirements make them unattractive to the firm given its profit opportunities in its home market. As a result, neither firm registers any sales to consumers outside of its home segment (Figure 4).

Demand structure and technology competition

As the overlap between value trajectories increases, the satisfaction of its home segment's functional demands leads each firm towards earlier satisfaction of the functional requirements of consumers in the foreign segment. Firms face incentives to pursue higher-end consumers within their home segment and, simultaneously, are tempted by the

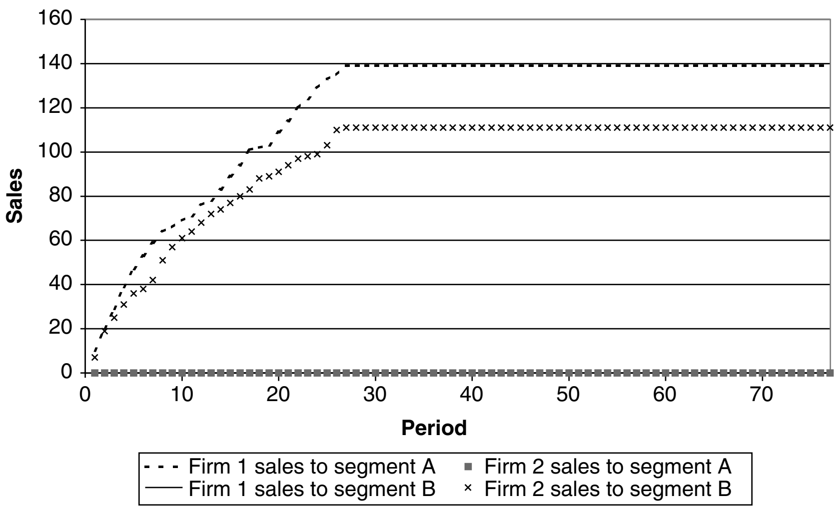

Figure 4. Isolation dynamics ($\gamma_A = 0.9$, $\gamma_B = 0.1$), sales by segment

presence of a new set of consumers. Because demand for functionality matures earlier at lower functional levels, lower-end consumers provide the entry point for foreign technologies to capture market share with lower prices. Competition emerges when the volume of relevant consumers in the foreign segment is sufficient to offset the price reductions required to attract these consumers.

Competitive convergence

When preference overlap is symmetric, both firms face broadly similar market landscapes. Figure 5 shows representative results for market conditions with $\gamma_A = 0.6$ and $\gamma_B = 0.4$. With sufficient preference overlap and technology development, one firm finds the marginal consumer in the foreign segment that has the effect of redirecting its development efforts and pricing policies towards invasion.[17] The transition to convergence is evident in Figure 5(a), which shows the sales of each firm to each segment. Firm 2 is first to penetrate its rival's segment. Key to Firm 2's ability to attract consumers from segment A, given the presence of Firm 1's functionally superior product (from the perspective of all segment A consumers), is the consumers' decreasing marginal utility from performance improvements which is reflected in their decreasing willingness to pay for improvements beyond the minimum requirements. By period 10, the performance provided by both firms more than doubles the threshold requirements of their lowest-end consumers. Decreasing willingness to pay, which effectively increases the importance of price differentiation as functionality improves, allows

[17] In the simulation the specific location of consumers in the space, idiosyncratic for each run, determines the firm will be first to redirect its activities to penetrate its rival's segment. Thus, while the dynamics are identical across all runs, the specific identity of the firm varies by run.

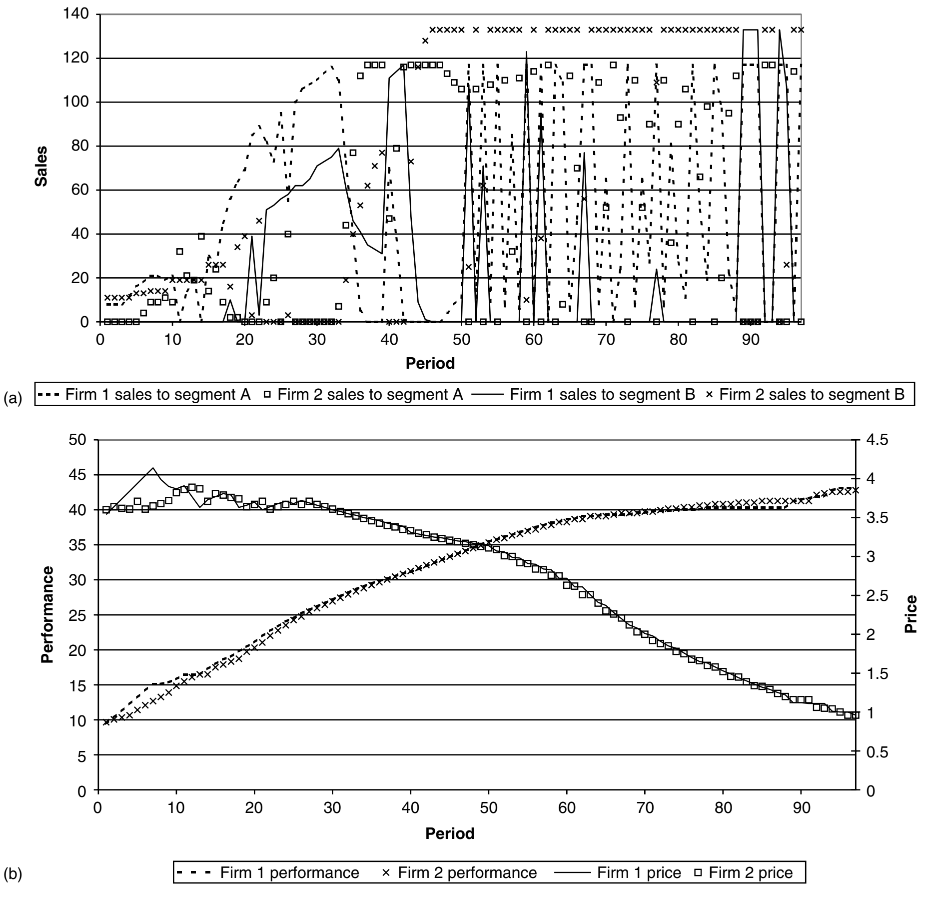

Figure 5. Convergence dynamics ($\gamma_A = 0.6$, $\gamma_B = 0.4$): (a) firm sales by segment; (b) price and performance by firm

Firm 2's functionally inferior product to be perceived as the better value by lower-end consumers in segment A, whose requirements are satisfied by both alternatives. Figure 5(b) shows the firms' price and performance positions over time.[18]

Firm 2's redirection of innovation efforts towards price affects the innovation incentives that Firm 1 faces. Firm 1 is faced with the option of matching its rival's price cuts, or holding back from following suit, exploiting the presence of high-end consumers who value its functional superiority (along their value trajectory) and who will support its higher prices. Note that with every development step, Firm 1's product offer becomes relevant to a larger set of consumers in segment B. Thus, even with a focus on its home segment's value trajectory, Firm 1's incentives to pursue segment B customers increase. The resulting dynamic of competitive convergence, in which both firms pursue each other's markets, is quite stark in the later periods shown in Figure 5(a).[19]

Competitive disruption

When the preference overlap between segments is not symmetric, progress along the different value trajectories leads firms to view different demand landscapes. Figure 6 shows representative results for market conditions with $\gamma_A = 0.9$ and $\gamma_B = 0.5$.

[18] In all figures functional performance is measured as products' Euclidean distance from the origin, $|\mathbf{F}_j|$.

[19] The 'trivial' case of convergent competition is when heterogeneity in either the demand or supply environments is eliminated. Thus, under conditions of high preference overlap, the technologies compete for what increasingly resembles a single market segment, giving rise to competitive convergence. Similarly, when the initial positions of the technologies are sufficiently close, the distinction between the two technologies disappears, also giving rise to competitive convergence.

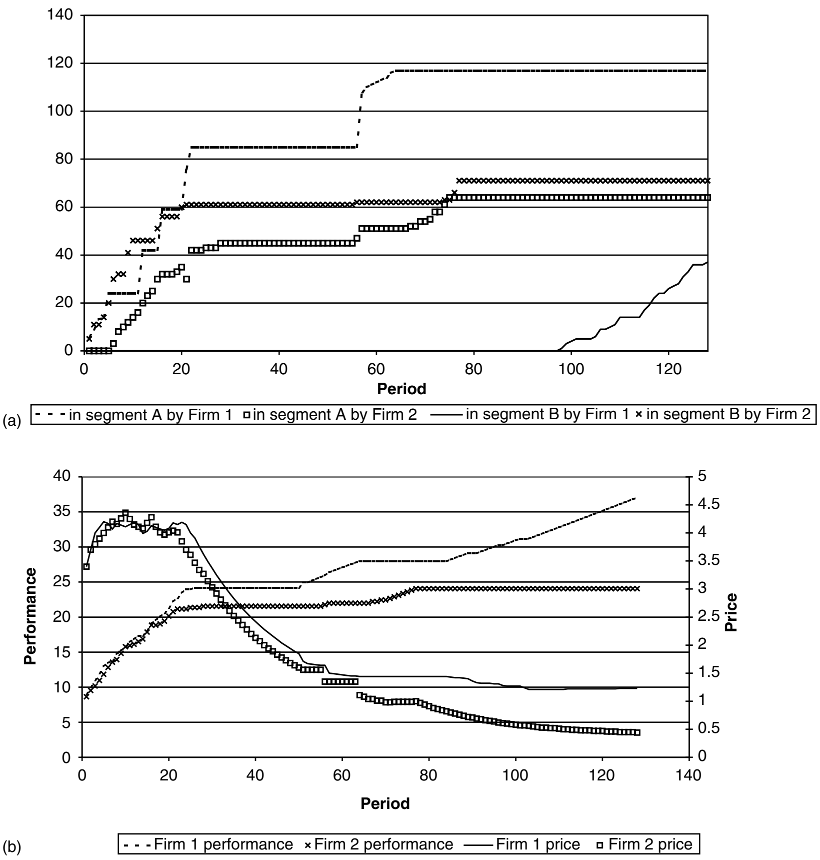

Figure 6. Disruption dynamics ($\gamma_A = 0.9$, $\gamma_B = 0.5$): (a) consumers with satisfied functional requirements by segment; (b) price and performance by firm; (c) firm sales by segment; (d) price/performance and price along segment A's value trajectory

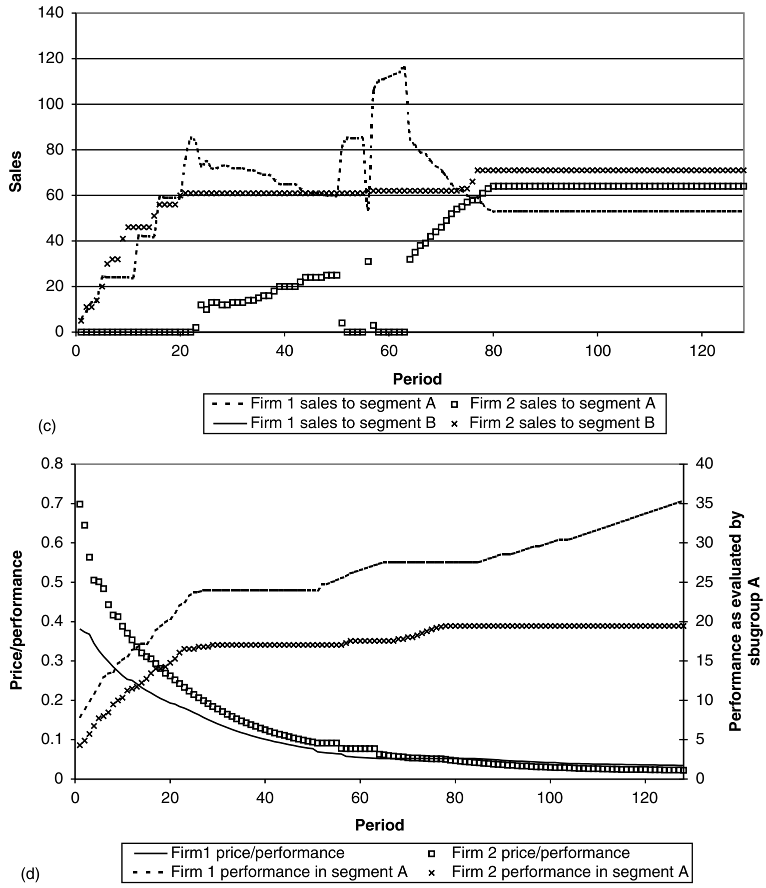

Figure 6. continued

This case characterizes the desktop computer (segment *A*)–notebook computer (segment *B*) markets for hard disk drives discussed above. Under such asymmetrical preference conditions, progress along the value trajectory of segment *B* leads to faster natural progress along the value trajectory of segment *A* than vice versa.

Figure 6(a) shows the number of consumers in each segment whose functional requirements are satisfied by each firm's technology. In period 6, Firm 2's product becomes functionally relevant to the segment *A* consumer with the lowest functional requirements. As shown in Figure 6(b), Firm 2 gains its first customer from segment *A* in period 23. This first sale outside its home segments corresponds to a price decrease, evident in Figure 6(c), which shows the price and absolute performance, $\mathbf{F}_j$, of each firm's offering.

Figure 6(d) graphs the price/performance and performance curves for each firm's offering as measured along segment *A*'s value trajectory. Significantly, it shows that at the time that Firm 2 is making inroads into segment *A*, its product offers lower performance and a worse price/performance level than does Firm 1's product.[20] The dynamics behind this disruption are further examined in the Discussion section.

While progress along segment *A*'s value trajectory does eventually allow Firm 1 to satisfy segment *B*'s functional requirements (period 98 in Figure 6a), it lags Firm 2 and is effectively precluded from pursuing the segment. Because of the preference asymmetries between segments *A* and *B*, Firm 1 is fighting an uneven battle for market share. At equal rates of innovation, following segment *A*'s value trajectory will attract

[20] Firm 2's price reduction ultimately provides for a more attractive price/performance offer (still at a lower absolute performance level) in period 74 and beyond but, as seen in the figures, this transition does not affect its market performance.

fewer consumers from segment *B* than vice versa. Further, as Firm 2 begins to address the functional requirements of segment *A*, Firm 1 faces pressure to justify its price to its existing high-end customers and responds to this competitive threat by focusing on providing increasing levels of performance. Firm 1 is thus driven further and further upmarket by a combination of market incentives and competitive threats.

MODELS, SIMULATIONS, AND REALITY

Drawing on Christensen's rich inductive research, this paper presents a model that strives to offer a parsimonious explanation for the dynamics of technology disruptions. The intent of the model is to focus on the essential demand-side drivers that shape the emergence of competition, particularly competitive disruption. As such, the model does not seek to dispute the importance of factors such as resource allocation, organization design, or resource dependence. Rather, by isolating the effects of demand structure on competition, the model should aid future research to more precisely consider the impact of such complementary factors.

The value of formalizing the model is that it brings to light implicit links and assumptions that lie unexplored in the inductive work (cf. Nelson and Winter, 1982; Saloner 1991; Malerba *et al.*, 1999). Having identified what he believes are the key features driving the phenomenon, the modeler is forced to make explicit the relationships between these elements. It was through this process of explication that many of the most interesting links in the present model were revealed. For example, in approaching the model, it was evident that consumers' reservation prices and product quality improvements would be important factors to include. In characterizing the evolutionary rules of the model, however, it became clear that these two factors must be linked—how does reservation price change with quality improvement? Recognizing the implications of consumers' decreasing marginal returns from performance improvements for their willingness to pay for new products turned out to be one of the most powerful realizations of the model. Similarly, building the model required characterizing the utility functions of different market segments according to their relative preferences for functional attributes. This posed the novel requirement of relating segment preferences to each other, and resulted in the creation of the grammar of preference overlap and preference symmetry to characterize demand structure.

The model is a focusing tool that helps interpret and organize the richness of empirical observation. In turn, the model's structure and results raise further questions for empirical exploration—e.g., what is the actual 'shape' of decreasing marginal returns; how does the way firms and consumers perceive preference overlap affect their definition of industry structure and industry boundaries; are price reductions subject to decreasing returns in the way functional improvements are; can firms affect the onset of decreasing returns to their customers? Even as they provide some logical closure on puzzles raised by earlier observations, the model's implications provide impetus for further empirical investigation.

The model is, by definition, a simplification. In the present model, the simplifying choices are driven by the goal of creating a baseline model that isolates the influence of demand structure on the emergence of competition. While factors such as asymmetric firm capabilities, asymmetric market segment sizes, and economies of scale could be incorporated into the model structure, they have been excluded from the present discussion to reduce the complexity involved in interpreting drivers of the model results.[21] The structure of the current model does not lend itself to the exploration of firm-level decisions, such as decisions to invest in alternative technology opportunities. The incorporation of factors such as resource allocation and resource dependence, which operate at the intrafirm level, would require a different modeling approach that pays explicit attention to the internal dynamics of decision making and cognition. While unexamined here, the relationships between market size, organization structure, credit allocation, and managerial incentives certainly offer a rich context for modeling explorations.[22]

[21] See Adner and Zemsky (2001) for a game theoretic examination of these relationships.

[22] See Sastry (1997) and Gavetti and Levinthal (2000) for illustrative examples of how simulation models can be applied to explore intraorganizational change processes.

DISCUSSION

The model developed in this article explores the influence of the structure of consumer demand on technology rivalry. By examining heterogeneity in consumer requirements and preferences, and by relating these factors across market segments, the model offers a basic grammar for characterizing the structure of demand and offers a new perspective on the emergence of competition. As technologies develop they increasingly satisfy consumers within their target market segments and may also become relevant to consumers in other segments. Categorizing demand structure according to preference overlap and symmetry highlights the differential market incentives that firms face as their technologies advance. When consumers face diminishing marginal returns to performance improvements, technologies that offer lower relative performance at lower price become increasingly attractive. In the face of continued performance improvements, this dynamic may lead to a blurring of the market's underlying heterogeneity which, in turn, influences the emergence of different competitive regimes.

The model sheds light on the important phenomenon of disruptive technologies (Christensen, 1997). Consider Christensen's explanation of why desktop computer users opted to purchase 3.5-inch hard disk drives when they offered lower capacity at a worse dollar-per-megabyte value than their 5.25-inch rivals:

> Why did the 3.5 inch drive so decisively conquer the desktop PC market? A standard economic guess might be that the 3.5-inch format represented a more cost-effective architecture: If there were no longer any meaningful differentiation between two types of products (both had adequate capacity), price competition would intensify. This was not the case here, however. Indeed, computer makers had to pay, on average, 20 percent more per megabyte to use 3.5-inch drives, and yet they *still* [italics in original] flocked to the product. Moreover, computer manufacturers opted for the costlier drive while facing fierce price competition in their own product markets. Why?
> Performance oversupply triggered a change in the basis of competition. Once demand for capacity was satiated, other attributes [size; power consumption], whose performance had not yet satisfied market demands, came to be more highly valued ... (Christensen, 1997: 166–167)

But why should desktop users, who had never before been concerned with issues such as power consumption, and for whom energy costs represent a negligible expense, suddenly choose to give up capacity for reduced energy use? The answer is not immediately apparent.

The current model offers an alternative explanation—that the desktop users were *not* choosing 3.5-inch hard disk drives due to their new attributes, but rather for their lower price—their lower price as measured not on a dollar per megabyte basis but rather on the basis of *unit* price. *That is, consumers with sufficiently satisfied functional requirements are more concerned with differences in absolute price than with differences in price/performance points.*

In support of this proposition, consider Figure 7, which shows the volume weighted average price of hard disk drives from 1984 to 1990, the years spanning the critical substitution period for 3.5-inch for 5.25-inch drives. Throughout this period, the unit price of the 3.5-inch drives is below that of 5.25-inch drives.

Viewed through a demand-based lens, the technology dynamics observed in the hard disk industry can be interpreted as follows: preference asymmetries are fundamental to shaping firms' incentives in a way that leads to the technology dynamics observed in the hard disk drive industry. Following the arguments made here, the critical factor driving the displacement of 3.5-inch for 5.25-inch hard drives was not the latent desire of desktop users for smaller, more energy-efficient disk drives; rather, it was that along with these other features, notebook users valued improvements in capacity—the attribute considered most critical by desktop users. Because the evaluation criteria of desktop users were subsumed by the criteria of notebook users, the developers of 3.5-inch technology, following the notebook segment value trajectory, quite naturally began to satisfy users in the desktop segment. As such, facing higher volumes in the broader market, the 3.5-inch firms had greater incentives to pursue a low price strategy.

Having achieved sufficient storage capacity to meet the minimum requirements of some low-end desktop users, 3.5-inch technology firms still had to contend with a 5.25-inch technology that offered consumers greater absolute capacity at a better price/performance ratio. The current analysis suggests that the essential aspect of consumer choice which allows for disruptive displacement may be consumers' decreasing marginal utility from

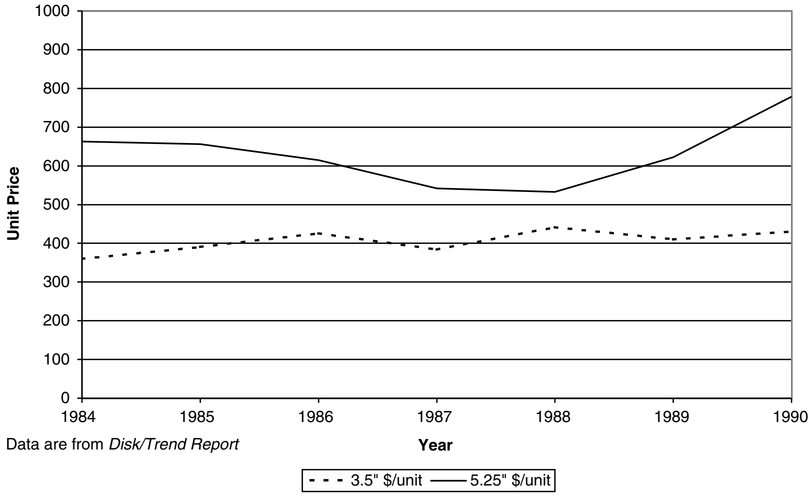

Figure 7. Average unit prices for 3.5 inch and 5.25 inch hard disk drives, 1984–1990

performance improvements beyond their requirements, rather than a new found appreciation for previously marginal attributes. This decreasing marginal utility translates into a decreasing willingness to pay for improvements. Thus a critical factor in consumers' decisions, once their requirements are met, is absolute price—while 5.25-inch technology was cheaper in price/performance terms, because the absolute performance of 5.25-inch drives was much higher than 3.5-inch drives, 5.25-inch drives were more expensive on a unit basis.[23]

The logic of decreasing marginal utility complements the notion of performance oversupply. It presents an even more fundamental aspect of consumer choice in that it accounts for changing behavior in the absence of the introduction of new attributes. Further, this logic suggests that information about the state of demand can be ascertained not only by observing the relative valuation of attributes, but also by observing consumers' willingness to pay for the total product at it evolves and improves. It also suggests that the drivers of the disruptive technology's adoption differ between its initial home segment and the mainstream; a difference which may have implications for how firms should organize for market entry (Moore, 1991).

At early stages of technology development, before performance is sufficient to satisfy consumer requirements, the issue of price is irrelevant. At later stages, when consumers' performance requirements are well satisfied and their willingness to pay for additional performance improvements has diminished, performance gains lose their efficacy as competitive actions. It is during the middle part of development that price/performance is a critical factor. Technology disruptions are more likely in this later stage, in which consumers may be willing to accept a worse price/performance offering if its absolute price is sufficiently low. This dynamic, driven by consumers' decreasing marginal returns from performance improvements, speaks to the increasing importance of price as technologies surpass consumers' requirements.

This logic informs the response to the question of 'When are technologies disruptive?' and helps distinguish between inferior technologies and disruptive threats. Christensen suggests that disruptive threats can be recognized by identifying the point of intersection between performance provided by a new technology and performance demanded by the existing consumers. This advice can now be further refined: first, the degree of preference overlap between the new technology's existing customers and the incumbent's segment specifies the magnitude of the impact that sustaining innovations along the preference lines of one segment will have on consumer evaluation in the

[23] Christensen states that incumbents have higher cost structures than entering rivals so that they need higher margins to survive. In the context of the model, this speaks to asymmetries in firms' initial cost positions and their abilities to engage in cost-reducing process innovations. To the extent that incumbents' process innovation options are limited, they will have an even harder time holding on to less demanding consumers and lose market share at the low end of the market.

other segment. Second, the degree of preference asymmetry specifies firms' differential incentives to compete for new market segments. Finally, critical to a disruptive outcome is the price at which the invader offers its product. The attacking firm must have the incentive and ability to offer its technically inferior, yet nonetheless satisfactory product at a sufficiently lower unit price to consumers than its rival (e.g., 3.5-inch disk drives displaced 5.25-inch drives, but notebook computers have not displaced desktops from their core markets even though they offer sufficient processing power along with benefits such as smaller size, lower weight, and lower power consumption). While disruption is enabled by sufficient performance, it is enacted by price. Thus, to identify potential disruptions, managers should plot not just performance-provided and performance-demanded curves, but also the price trajectories of the competing offers.

A demand-based view of the emergence of competition

In examining the development of firm capabilities (Wernerfelt, 1984; Teece, Pisano, and Shuen, 1997) and the nature of firm competition (Porter, 1980; Hamel and Prahalad, 1994), the strategy literature has tended to exhibit a 'supply-side' bias. Focused on firms' activities and interactions, the literature has largely overlooked the role of the demand environment in which these interactions take place. The demand context, however, affects both the immediate success of firms' activities as well as the nature of future activities. A demand-based view, focused on how firms' offers are evaluated in the market, complements the resource-based view that has focused on how firms create these offers.

The demand landscape shapes the opportunity structure that firms face and affects individual firms' incentives to innovate. Firms' innovation activities, in turn, affect consumers' expectations and, through these expectations, the demand environment faced by rival firms. Of particular interest is how, as a technology's performance begins to address the needs of consumers in multiple market segments, the distinction between these segments is blurred, leading to radical changes in firms' competitive positions. By focusing on the interaction between firms and their environments, a demand-based view of competition presents a complementary approach to examining many of the dynamics that are of interest to the strategy field and offers a link between the evolution of firms' individual activities and the evolution of competition.

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