A Demand-based View of Technology Competition:

Demand structure and technology displacement

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This paper investigates how the structure of market demand affects the nature and extent of competition over consumer subgroups in the market. It develops an analytic model to examine how the satisfaction of consumers' requirements and the relationships between consumers' preferences interact to affect competitive interactions. The model, tested using simulation, reveals demand-side influences on the emergence of three distinct competitive regimes: *isolation*, in which technologies do not interact throughout the course of their evolution; *convergence,* in which technologies evolve to compete head-on for the same consumer groups; and *displacement*, in which one technology cedes dominance of its home market to its rival. The model highlights the critical role played by price in influencing technology displacements and sheds some new light, supported by empirical data from the disk drive industry, on the important phenomenon of disruptive technologies.

INTRODUCTION

A primary concern for the field of strategic management has been understanding the drivers of firm heterogeneity. While the dominant level of analysis has fluctuated between the organization of industry competition (Bain, 1956; Porter, 1980) and the development of firm level capabilities (Penrose, 1958; Wernerfelt, 1984; Teece, Pisano and Shuen, 1997) the thrust of the analysis has been focused on firms' activities and interactions, and has tended to overlook the demand environment in which these activities and interactions take place. The demand context, however, affects both the immediate success of firms' activities as well as the nature of future activities. Learning is driven by feedback (March and Simon, 1958; Cohen and Levinthal, 1989). Because feedback is dependent on context, the choice of context is critical to what learned. Understanding the heterogeneous nature of market contexts is therefore critical to understanding the process of organizational learning and its effect on strategy and capability development. The structure of the demand landscape, the distribution of consumer needs and preferences, 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. In this way the structure of demand links the evolution of individual firms' activities and capabilities with the evolution of competition.

This paper investigates how the structure of market demand affects the nature and extent of competition over consumer subgroups in the market. Specifically, this paper examines how the satisfaction of consumers' requirements and the relationships between consumers' preferences interact to affect the emergence of three distinct competitive regimes: *isolation*, in which technologies do not interact throughout the course of their evolution; *convergence,* in which technologies evolve to compete head-on for the same consumer groups; and *displacement*, in which one technology cedes dominance of its home market to its rival. The paper develops demand constructs based on Lancasterian demand theory (Lancaster, 1979, 1991) and incorporates them into an evolutionary economic model (Nelson and Winter, 1982) of technology development. In its essence, the model examines the nature of competitive interactions that arise under varying configurations of demand, while controlling for asymmetries in initial resource endowments and technological potential. The model is applied using computer simulation to examine the effects of demand structure on technology competition with particular attention paid to identifying the demand-side drivers of technology displacement.

Technology Displacement

Instances of technology displacement hold a particular interest for managers and strategists alike. The classic stories of innovation hinge on the notion of technological displacement – sail ships by steam; steam engines by diesel; vacuum tubes by transistors and later transistors by microchips. These dynamics have generally been approached using 'supply side' explanations which focus on the interactions of firms and firm capabilities. At the technology level, the cause of such displacement has often been attributed to the exhaustion of the incumbent technology's development trajectory (Foster, 1986; Utterback and Abernathy, 1978). At the firm level, the difficulty in managing displacement threats is often attributed to an unwillingness to cannibalize existing technology investments (Kamien and Schwartz, 1982); organizational inertia (Hannan and Freeman, 1977; Tushman and Romanelli, 1985); 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 displacements reveals that such transitions are not necessarily due to the incumbent technology's inherent limits (Christensen, 1992; Cooper and Schendel, 1976; Henderson, 1995) or the new technology's ability to provide strictly superior performance (Christensen, 1997; Levinthal, 1998) While these obstacles are clearly important, numerous cases of aggressive innovators who did not suffer from these handicaps yet none the less mismanaged the challenge of technological transition suggest the need for additional explanations (Cooper and Schendel, 1976; Smith and Alexander, 1988; Christensen and Rosenbloom, 1995).

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 technology projects (von Hippel, 1988; Lynne, Morone and Paulson, 1996), business strategy (Kim and Mauborne, 1997; Day, 1990) and the broader evolution of technological trajectories (Abernathy and Clark, 1985; Christensen, 1997; Tripsas, 1999).

The most influential expression of a demand side role in technology displacement has been Christensen's examination of disruptive technologies in the context of the hard disk drive industry (Christensen and Bower, 1997; Christensen, 1997) which suggests that displacement of competing technology generations can be better understood by focusing on the relationship between performance demanded by consumers and performance provided by technologies. The model presented in this paper extends the current discussions of the role of demand in influencing competition by offering an analytic structure for evaluating how demand structure affects technology competition. By using the structure of demand as a lens for understanding the evolution of competition the model also addresses some open questions regarding the nature of disruptive technologies and offers an alternative explanation of how changes in the demand landscape are both driven by, and drivers of, changes in technology development. In particular, the model highlights the critical role played by price in influencing technological disruptiveness. This finding is supported by empirical data from the disk drive industry.

After introducing structural relationships among aspects of the demand landscape in section 2, a formal evolutionary model is introduced in section 3. The model considers the changes in consumer's decision criteria which accompany technological changes by introducing the issues of price and consumer's willingness to pay for improved technology performance as factors in the demand landscape. The results of the simulation analysis, presented in section 4, examine how this changing valuation of performance interacts with the relative distribution of functional preferences in the market to affect firms' interactions, leading to three distinct competitive regimes: isolation, convergence, and disruption. The discussion in section 5 identifies consumers' decreasing marginal utility from performance improvement beyond their requirements as a critical demand-side driver of technology displacement, and shows that the displacement dynamics observed in earlier studies can be explained in terms of the increasing importance of absolute price as performance requirements are met, rather than new found appreciation for previously marginal attributes. Section 6 presents broader conclusions about market demand as a link between the evolution of capabilities and competition.

DEMAND STRUCTURE

The aspects of demand which motivate this paper concern choice at the level of individual consumer and of consumer groups. The present section structures the demand environment according to consumers' absolute functional requirements, their willingness to pay for performance beyond their requirements, and by their relative preferences for performance beyond their requirements. The choice constructs themselves are well established in consumer behavior theory. The novelty introduced in this paper lies in relating the preferences of different market subgroups in a way that identifies demand conditions which may alternately lead to the emergence of competitive isolation, convergence, and displacement.

Requirements, Preferences, and Consumer Utility

Individual consumers have absolute requirements that come into play in the course of evaluation. The notion of thresholds, critical performance levels which 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). A performance threshold specifies the level of performance below which a consumer will not accept a product *at any positive price.* A product that falls below a consumer's performance threshold is, for that consumer, 'junk'. Consumers' performance thresholds are determined in part by inherent task requirements and in part by context and, as these factors vary for individual consumers, their performance requirements will differ as well. Thus, consumers who are aligned with regards to the definition of what constitutes performance improvements may still differ with regards to the minimum acceptable levels of performance.

In addition to absolute requirements, different individuals may use different criteria to evaluate options. While they may be aware of all the possible functional dimensions along which products can be evaluated, different consumers will have different relative preferences regarding the importance of these dimensions. While consumers purchase whole products, a long tradition of work in marketing, decision science, and economics (Griliches, 1961; Lancaster, 1965, 1979; Green and Wind, 1973; Trajtenberg, 1990) 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.[1] The value of disaggregating goods into component characteristics is that it allows for the consideration of how product modifications affect demand. While functional requirements indicate initial thresholds, relative preferences dictate the evaluation of improvements which exceed these requirements and thus dictate individual consumers' perceptions of aggregate 'performance'.

Beyond functional evaluation, consumer choice is obviously influenced by the matter of price. Here too, we may expect to find heterogeneity among consumers, even those with similar functional preference structures. Differences in consumers' willingness to pay may be driven by differential budget constraints. They may also be driven by non-budgetary considerations; for example differences in the ability of the customer to exploit the product. Such heterogeneity may stem from customer's internal resources (Barney, 1986) and capabilities (Amit and Schomaker, 1990) 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 that 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; whereas a similar firm, 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[2]. At the same time, consumers face diminishing 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. In a competitive context this responsiveness to functionality improvements may force firms to continue to enhance functionality even when such enhancements have little effect on consumers' willingness to pay.

Consumer Groups, Value Trajectories, and the Structure of Demand

Consumers can be clustered into market subgroups[3] according to the similarity of their relative preferences for functional characteristics. Consumers with shared preference structures share a common definition of product *performance* and thus agree in their evaluation of changes in a products functional components. Consumers with shared preference structures will agree as to the relative ordering of their choices when confronted with a choice among a set of products; consumers with increasingly divergent preference structures will increasingly disagree as to this ranking**.** As a useful shorthand we can define consumers' *value trajectories* as characterizing consumers' relative preferences for functional attributes. As illustrated in Figure 1, the value trajectory graphically captures the direction of propagation of the market subgroup's indifference curves as they progress toward higher utility levels.[4] Consumers' evaluation of products' functional performance is therefore determined according to the products' projection onto the value trajectory – the farther out on the value trajectory the projection, the greater is product's functional performance as determined by the consumers' relative functional preferences.

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Value trajectories can be used map relationships between the relative preferences of different market subgroups. Using value trajectories to examine the overlap between market subgroup's relative preferences and the symmetry of this preference overlap clarifies the differential market incentives firms face in choosing their innovation activities which in turn drive the emergence and evolution of competition. These relationships are illustrated below and developed formally in the context of the model in section 3.

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 (PC), who value storage capacity much more than portability; consumers in the market for personal digital assistants (PDA), who value portability much more than storage capacity; and consumers in the market for notebook computers (NC) who value capacity and portability in equal measure.

------------INSERT FIGURES 2a and 2b ABOUT HERE

The *preference overlap* between these subgroups 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 subgroups' agreement on the level of product performance. Thus, as illustrated in figure 2a, 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 increase, as illustrated in Figure 2b for the PC and NC groups, these evaluations converge. Here, the PC groups derived utilities of 3 and 2.7 from products A and B respectively are in much 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 subgroup's satisfaction with a given product's functionality is indicative of the satisfaction of another group – the performance shadow cast on a subgroup's value trajectory by progress along its counterpart's trajectory. When individual firms initially pursue different market subgroups, the subgroups' preference overlap is an indicator of the ease with the firms can invade other market niches.

While the magnitude of preferences overlap speaks to the absolute degree of preference similarity, the *symmetry of preference overlap* refers to the extent to which, for a given performance level along a subgroup's value trajectory, the performance perceived by members of the other subgroup is the same; that is, the difference between the factors by which each group discounts progress made along the other's value trajectory. Thus, 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 subgroup's value trajectory will provide a different level of utility to members of the other subgroups than will a product positioned at the same distance along the other subgroup's value trajectory provide to members of the first subgroup. 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 subgroups, the symmetry of preference overlap plays an critical role in structuring their differential incentives for pursuing other subgroups.

Conceptualizing demand according to consumers' requirements and preferences suggests a demand landscape that co-evolves with technology development: As consumer's 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 utility of increase, 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' assessments procedures lead to changes in firms innovation incentives which in turn affect consumers' decisions in future periods.

MODEL STRUCTURE

This section formalizes the demand constructs presented above and develops an evolutionary model of the role of the structure of demand in the emergence of competitive interactions. The model follows in the Lancasterian tradition of conceptualizing the market space along attribute dimensions. It extends previous applications of characteristics demand models by examining how the structure of demand affects firms' development choices throughout a technology's evolution and how these two 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 subgroups.

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.[5] In every period, 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.

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. Although preferences are stable, consumer purchase decisions vary as product offerings change over time. The model assumes that there are no switching costs, consumption externalities, or economies of scale. Further, consumers are assumed to be well informed, in that they have perfect information about product performance[6], but are short sighted in that they do not consider postponing their purchase in expectation of future improvements. Given a choice among a set of acceptable products, a consumer will select the product that maximizes his utility. There are two hundred and fifty consumers in the market, evenly distributed between the two subgroups. In every period the entire population of consumers is exposed to the available products and each consumer selects his own best choice. To further simply the analysis, firms are not subject to capacity constraints.

Consumer Choice

In the model individual consumers are characterized by their threshold requirements and their relative preferences for improvements beyond these requirements. Each individual has a utility threshold, U_{i0}, which a product must meet to be considered for purchase. An individuals derives utility from a given product offering according to its functional performance and its price. Performance is determined by the functionality of the product in excess of the consumer's functional threshold requirements, $\mathbf{F}_{i0}$, and by the consumer's relative preference for each dimension of functional performance, the consumer's value trajectory, which is specified by the parameter γ[7]. The consumer's tradeoff between product functional performance and price is specified by the parameter α.

The market space is defined by two functional dimensions, X and Y. B_{ij} is the functional performance 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} on the two functional dimensions:

$$(eq.1)\quad B_{ij} = B_i\left(\overline{F}_j\right) = \begin{cases} \left(F_{jX} - F_{iX}\right)^{\gamma}\left(F_{jY} - F_{iY}\right)^{1-\gamma} + 1 & if \quad \left(F_{jX} - F_{iX}\right)\left(F_{jY} - F_{iY}\right) \geq 1 \\ 0 & otherwise \end{cases}$$

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, P_j, and functional performance[8]:

$$(eq.2)\quad U_{ij} = U_i\left(\overline{F}_j, P_j\right) = \left[B_{ij}\right]^{\alpha_i}\left(\frac{1}{P_j}\right)^{1-\alpha_i} \qquad , where \quad 0 < \alpha_i < 1.$$

Consumers will reject any product that does not meet both their functionality and 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 satisfies his functionality requirement, $B_{ij} = 1$, is:

$$(eq.3)\quad P_{i0} = \left(U_{i0}\right)^{\frac{1}{\alpha_i - 1}}$$

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

(eq. 4) $P_{ij} = P_{i0}(B_{ij})^{\frac{\alpha_i}{1-\alpha_i}}$

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 subgroups and all members of a market subgroup, m, have the same relative functional preferences $\gamma_{m.}$ The value of γ_m thus specifies a market subgroup's value trajectory. Graphically, for the two functional dimensions the degree measure of the value trajectory is $90^{\circ}(1-\gamma)$.

For two market subgroups A and B whose derived utility from two functional attributes X and Y is given as:

$$(eq.5a) \quad U_A = F_X^{\gamma_A} F_Y^{1-\gamma_A}$$
$$(eq.5b) \quad U_B = F_X^{\gamma_B} F_Y^{1-\gamma_B} \qquad where \quad 0 \le \gamma_A, \gamma_B \le 1$$

preference overlap is defined as:

$$(eq.6) \quad preference\ overlap = 1 - |\gamma_A - \gamma_B|$$

The greater the preference overlap, the greater the subgroups agreement on the rank ordering of alternatives. When preference overlap is zero, the subgroups' preferences are entirely divergent such that changes which affect on subgroup's evaluation have no effect on the other's evaluation. When preference overlap is unity, the subgroups evaluation trajectories coincide such that the two subgroups behave as a single group.

Symmetry of preferences refers to the extent to which each subgroup's preferences project onto the others'. Preference symmetry, measured as the relative degree to which each subgroups value trajectory favors either functional attribute, is defined as:

$$(eq.7)\quad \textit{preference symmetry} = \left|0.5 - \gamma_A\right| - \left|0.5 - \gamma_B\right|$$

As the relative balance measure approaches zero, preference overlap becomes increasingly symmetric. When the relative balance measure is positive (negative), the projection of subgroup B's value trajectory on subgroup A's value trajectory is greater (less) than A's is on B's.[9]

Technology Development

In the model, technology initiatives are characterized by their functional attainment on each of the functional dimensions and by a production cost. Technologies are developed by firms which introduce products to the market on the basis of their technology positions with the goal of maximizing profits in the current period. Firms are not subject to capacity constraints. Each firm is initially endowed with a technology with initial functional and cost characteristics. In the course of the simulation firms develop their product technologies in response to the opportunities they perceive in the market place. 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, $\mathbf{F}^{prod}$, and leads to a fixed production cost increase, C^{prod}. In the spirit of an evolutionary approach, $\mathbf{F}^{prod}$ 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:

(eq.8a) $\mathbf{F}_{j,\,t+1} = (F_{jX,\,t} + \Delta F_X), (F_{jY,t} + \Delta F_Y)$ where $[(\Delta F_X)^2 + (\Delta F_Y)^2]^{1/2} = F^{prod}$

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

The choice of relative allocation of improvement determines the technology's development trajectory (Dosi, 1982). 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. This cost serves as a disincentive to meandering through the space or to changing trajectory for insufficiently substantial opportunities.

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:

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

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

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[10]. 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 also 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 them the greatest period profit. Firms are unable to evaluate potential consumer demand for changes that result beyond a single development action.[11] Firms are also 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 past activities of market rivals.[12]

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 to product to the market. The firm will develop an expectation of profits for each possible action which is determined by its production costs, development costs, and predicted market feedback. Similarly, the firm develops a profit expectation for potential process innovation by predicting market response to different price points given its reduced production costs. The firm will commit 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 analyzed using a computer simulation programmed in Pascal. The first procedures of the simulation initialize both 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, and the value trajectory along which functional improvements are judged. For the results reported in this essay, consumers were assigned to one of two evaluation trajectories and the population was evenly divided between them. The range of consumers' minimum functional thresholds was such that approximately twenty product innovation attempts were necessary to span the distance between the minimum requirements of the least and most demanding customer in the market. Consumers are distributed uniformly 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. 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[13]. 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 the yield highest expected profit. Third, every consumer then independently evaluates the available product offerings and decides on purchases as specified above. Finally, market outcomes are tallied and firms realize their actual market payoffs. These four basic procedures are repeated until a steady market state is reached.

The model is used to examine the behavior of two firms pursuing independent technology initiatives in a market with two consumer subgroups. The value of γ for each subgroup is manipulated to examine the effects of preference symmetry and overlap on the evolution of technology competition. Each firms' technology is initially positioned along the value trajectory of one of the market subgroups. The effects of varying the subgroups' preference overlap and symmetry on the emergence of competition are examined.

The results of the simulation are robust with respect to the qualitative behaviors that are of interest to this essay. In the representative figures that are shown in this section, the market space is seeded with 250 consumers who are evenly distributed between the two subgroups. 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 subgroup'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 runs, $\alpha = 0.2$, $F^{prod} = 1$, $C^{prod} = 0.1$, $\Delta_c = 0.05$. While changing parameter values affects the absolute magnitudes and rates of behaviors, the qualitative market partitioning patterns remains consistent throughout.

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 subgroups, Subgroup A and subgroup B.

At the start of the simulation Firm 1's technology position is aligned with subgroup A's value trajectory and Firm 2's technology position is aligned with subgroup B's value trajectory.

RESULTS

The behavior of interest in this simulation regards the nature and extent of rivalry over consumer subgroups in the market. In particular, we are interested in the way in which this rivalry is influenced by the structure of demand. As such, 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 penetration into the market subgroups with regards to both the satisfaction of consumers' requirements and consumers' actual purchasing decisions.

Three qualitatively distinct dynamics emerge during the course of the analysis. Under demand conditions of low preference overlap, the development dynamics lead to *isolation*, a pure partitioning of the market between the technologies, such that each focuses exclusively on its own subgroup. Under demand conditions of higher preference overlap, the development dynamics lead to the emergence of two distinct classes of competition. When the preferences are symmetrical between subgroups *convergent competition* is observed, 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 subgroup preferences are asymmetrical, however, *technology displacement* is observed. As the performance of both technologies advances beyond the basic requirements of a growing number of consumers within their own market subgroup, the technology serving the market subgroup whose preferences have the greater overlap with its counterpart faces greater marginal incentives to pursue consumers outside its own market subgroup than does its rival. This incentive is structured by both the structural asymmetry of preferences as well as consumer's decreasing marginal utility from performance improvements beyond their requirements. As its rival pursues consumers at the lower end of its market, the invaded technology faces greater incentives to focus on its higher end customers through performance improvements than to defend its position at the low end through price reductions. From the consumer's perspective the appeal of the invading technology, which offers neither higher performance nor higher price/performance, is based firmly on the issue of absolute price.

Demand structure and technology isolation

Isolation behavior, in which each technological initiative sells only to its immediate market is characteristic when the overlap in the functionality demanded by the market subgroups is small. Figure 3 shows representative simulation results for the low overlap case in which the two market subgroups have functional preference parameters $\gamma_A = 0.1$ and $\gamma_B = 0.9$. This case characterizes the PDA – desktop computer markets for hard disk drives example discussed above. Initially, technology initiatives satisfy the functional requirements of only their focal subgroup and development proceeds along a path that matches that subgroup's value trajectory. Because of the wide difference in relative preferences, technology development following one subgroup's value trajectory does not lead to significant improvement along the other subgroup's criteria. Firms' development and pricing decisions are thus substantially determined by the requirements of their home subgroups. As development proceeds, and functional attainment increases, the firms are able to satisfy the functional requirements of the lower end of the other market subgroup. 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 their alternative, the firm would need to lower prices well below the level it is able to charge its existing customers. Thus, while consumers outside the focal subgroup[14] are functionally visible, their price requirements make them irrelevant to the firm, given its ability to attract higher end users, who willing to pay higher prices, within the focal subgroup. As a result, neither firm registers any sales to consumers outside of its focal subgroup (Figure 3).

---------INSERT FIGURE 3 ABOUT HERE

Subgroups can be isolated due to differences in their relative preferences, such that development along one value trajectory will not lead to the core of the other subgroup. Alternatively, isolation can occur due to differences in the minimum requirements of the low functionality consumers in the subgroups, such that significant development along a seemingly valueless performance dimension is required before the initial consumers can be reached.

Demand structure and technology competition

As the overlap between value trajectories increases, the satisfaction of the focal subgroup's functional demands leads each firm towards greater satisfaction of the functional requirements of a set of consumers from the other subgroup. Firms face incentives to pursue higher end consumers within their home subgroup and, simultaneously, are tempted by the presence of a new set of consumers. Under conditions of preference overlap, firms are confronted with incentives to serve not only their focal subgroup, but to attempt to penetrate its rival's subgroup as well. Because demand for functionality matures earlier at lower functional levels, lower end consumers provide the entry point for 'out group' technologies to capture share with lower prices. In such regimes, the symmetry of the overlap will affect the competitive dynamics. During the course of product development, one firm will find a promise of greater total profit by reducing its price to attract consumers from outside its own subgroup. This price cut will attract consumers from its rival's subgroup, and also increase its sales to its own subgroup as consumers who had previously found its price too high enter the market at the lower price.

Convergent Competition

When supply conditions and demand conditions are symmetric, both firms face broadly similar market landscapes. Figure 4 shows representative results for market conditions with γ_A= 0.6 and γ_B= 0.4 such that the valuation of functional attributes by subgroup A is inversely proportional to subgroup B but, compared to the isolation case discussed above, the absolute overlap in relative functional preferences is significant. Under conditions of symmetrical preferences one firm will find the marginal consumer that will redirect its development efforts and pricing policies towards pursuit. Because this decision is dependent on the specific, idiosyncratic, distribution of consumers in the space, the determinant of which firm will be first to redirect its activities to penetrate its rival's subgroup is highly path dependent. The transition to convergence is evident in Figure 4a which shows the sales of each firm to each subgroup. Firm 2 is first to penetrate its rival's subgroup. Critical to Firm 2's ability to attract consumers from subgroup A given the presence of Firm 1's functionally superior product (from the perspective of all subgroup 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. This decreasing willingness to pay, which effectively increases the importance of price differentiation as functionality improves, allows Firm2's functionally inferior product to be perceived as the better value by lower end consumers in subgroup A whose requirements are satisfied by both alternatives. Figure 4b shows the firms price and performance positions over time.[15]

----------- INSERT FIGURES 4a and 4b ABOUT HERE --------

Firm 2's redirection of innovation efforts towards price affects the innovation incentives which face firm 1. Firm 1 is faced with the option matching its rival's price cuts, or hold back from following suit, relying on the presence of high end consumers who value its functional superiority (along their value trajectory) and will support its higher prices. Because Firm 1, which is reacting to the price moves made by Firm 2, can't rely on consumers in subgroup A to shift their buying decisions, its marginal profit incentives for changing trajectories are less than its rival's were when the price cut was initiated. In reducing its price to defend against the loss of its customers, however, Firm 1's incentives to pursue subgroup B customers themselves 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 4a.

Technology Displacement

When the preference overlap between segments is not symmetric, such that the evaluation criteria of one subgroup subsume the criteria of the other subgroup, the dynamics of technology displacement are a function of this asymmetry. Figure 5 shows representative results for market conditions with γ_A= 0.9 and γ_B = 0.5. This case characterizes the desktop computer (subgroup A) - notebook computer (subgroup B) markets for hard disk drives discussed above. Under such asymmetrical preference conditions, progress along the value trajectory of subgroup

B, which has relatively more balanced functional preferences, will lead to faster natural progress along the value trajectory of subgroup A than vice versa.

INSERT FIGURES 5a, 5b, and 5c ABOUT HERE --------

Figure 5a shows the number of consumers in each subgroup whose functional requirements are satisfied by each firm's technology. Firm 2 becomes first becomes functionally relevant to the subgroup A consumer with the lowest functional requirements in period 6. As shown in figure 5b, Firm 2 gains its first customer from subgroup A In period 23. This first sale outside it's home subgroups corresponds with a price decrease evident in Figure 5c, which shows the price and absolute performance, $\mathbf{F_j}$, of each firm's offering.

-------------INSERT FIGURE 5d ABOUT HERE-------

Figure 5d graphs the price/performance and performance curves for each firm's offering as measured along subgroup A's value trajectory. Significantly, it shows that at the time that Firm 2 is making inroads into subgroup A, its product offers lower performance and a worse price/performance level than does Firm 1's product.[16] This displacement dynamic is further examined in the discussion.

While, progress along subgroup A's value trajectory eventually leads Firm 1 to the satisfaction of subgroup B's functional requirements, at a fixed rate of technological advance, as figure 5a shows, this satisfaction occurs does not occur until period 98 – a much slower pace relative to its rival. Because of the preference asymmetries between subgroups A and B, Firm 1 is fighting an uneven battle for market share. At equal rates of innovation, following subgroup A's value trajectory will attract fewer consumers from subgroup B than vice versa. Further, as Firm 2 begins to address the functional requirements of subgroup 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 up market by a combination of market incentives and competitive threats.

DISCUSSION

The model developed in this essay explores the influence of the structure consumer demand on the emergence of competitive interaction. It does so while controlling for traditional sources of firm heterogeneity such as resource endowments, capabilities, strategic insight, and technological potential. The model clearly oversimplifies many of the factors that we know to be important in determining competitive outcomes (economies of scale, learning curves, S-curves; consumption externalities; multi-product offerings; uncertainty; etc.); this simplification, however, is the purpose of the modeling exercise – to provide a baseline understanding of the behaviors that can be expected purely on the basis of the structure of demand. Certainly such complications can be valuably explored in future work, but the baseline model itself offers several insights:

The analysis reveals asymmetry in consumer preference structures and consumers' decreasing willingness to pay for performance improvements to be critical demand factors that govern technology displacement dynamics. Heterogeneity in consumers' absolute performance requirements implies that individual consumers will vary in the degree to which a product technology at a given stage of development is capable of satisfying their requirements. Recognizing heterogeneity in relative preferences further suggests that consumers' assessment of functional improvements in given product technology will vary by subgroup. As such, consumers' requirements specify a product's viability, while consumers' relative preferences structure the incentives for product development.

The extent of market subgroups' preference overlap indicates the extent to which technology development directed as satisfying the functional demands of one subgroup will also lead to the satisfaction of the demands presented by the other subgroup. Greater preference overlap may thus lead firms to greater competitive interaction. In case when preference overlap is asymmetrical, this competitive interaction can itself be asymmetric as firms pursuing the needs of more functionally complex segments are able to satisfy functionally focused consumers to a greater extent than firms pursuing functionally focused segments are able to satisfy functionally complex consumers.

Disruptive technologies and market displacements

By explicitly examining the influence of demand structure on the emergence of competition, the model sheds light on the important phenomenon of disruptive technologies (Christenesen, 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..." (p. 166-7; 1997)

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 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 whose functional requirements are satisfied will are more concerned with differences in absolute price than with differences in price/performance points.*

--------- INSERT FIGURE 6 ABOUT HERE ----------

In support of this proposition, consider Figure 6, 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.[17]

Viewed through the market based lens suggested in this analysis, 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 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 desk top users. Because evaluation criteria of desktop users were subsumed by the criteria of notebook users, the developers of 3.5-inch technology did not need to divert any attention from progressing along the notebook users' value trajectory to evidence improvement in the eyes of desktop users.

Preference asymmetries, however, only explain firms' development choices, and do not address consumers' purchasing decisions. Having developed sufficient 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 is consumers' decreasing marginal utility of 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 offered lower price/performance point, the product as a unit was sold at a higher price than its 3.5-inch rival.,[18]

This logic of decreasing marginal utility is complementary to the notion of performance oversupply, but 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. As such, it 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.

One significant implication of the demand based view approach to understanding technology development is that the relevance of the traditional measure of technological efficiency, the price-performance ratio, is qualified by the level of performance provided relative to consumers' performance requirements. Initially, 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 – at later stages, consumers may be willing to accept a worse price/performance offering if its absolute price is sufficiently low. In a world in which no new rival technologies are introduced, this decreasing valuation of improvement leads to the commoditization of the product. If rival technologies are introduced, this decreasing valuation opens the door to the displacement and possible elimination of the incumbent technology.

This dynamic, driven by consumers' decreasing returns from performance improvements, speaks to the increasing importance of price as technologies surpass consumers' requirements. Thus, under conditions in which technology performance exceeds consumers requirements, the strategic focus should change from technology life cycle, whose critical aspect is the remaining potential for performance improvements, to a *demand life cycle* whose critical aspect is the value the degree to which consumers' value additional performance improvements.

While the displacement dynamics described above can lead to radical changes in market positions, the pace of these changes follows the pace of technological progress. As a technology's performance begins to address the needs of consumers in multiple market subgroups, the distinction between these subgroups is blurred. This blurring, however, is gradual, affecting an increasing portion of a given subgroup as the technology's performance progresses further along the subgroup's value trajectory. While a technology's advance may lead to convergence among some consumers in different market subgroups, the extent of the characterization of this convergence will depend on the technology's state and rate of development, which brings the discussion full circle to the importance of firms' capabilities in affecting technological progress and competition.

Rival technologies coexist for substantial periods before displacement takes place. Eventually, as suggested by the dynamics described above, incumbent technologies may be left behind as they lose the mainstream. Even after radical displacement, however, the possibility exists that these technologies find a niche among those consumers at the very high end of the performance trajectory whose needs are not entirely addressed by the new technology. Indeed, even in the classic examples of radical displacement we find evidence of these outliers -- yachtsmen who prefer sailboats to motor boats; audiophiles who prefer vacuum tubes to semiconductors; consumers who prefer fountain pens to ball points and mechanical to digital watches. In these niches, which represent the very high end of the performance trajectory and command a matching price premium, firms can survive and enjoy high margins, even if they do not have an option for high volume.

CONCLUSIONS

Heterogeneity is relevant to the study of technology strategy because it is a fundamental driver of the market's ability to simultaneously sustain multiple technological approaches. The impact of such diversity is brought to the fore when a technology serving one market subgroup displaces a rival in another subgroup. The demand based view offered in this paper complements the established approaches to competition and differentiation Focusing on the structure of heterogeneity offers a new approach to understanding the co-evolution of firms' incentives and their competitive interactions.

Firms development activities have the opportunity to affect consumers' marginal elasticity of substitution between the firm's product and other products available in the market.

The structure of demand, as regards the distribution of consumers' relative preferences, and the evolution of demand, as regards changes in consumers' valuations of performance improvements, affect firms' incentives to exploit this opportunity.

Categorizing demand structure according to preference overlap and symmetry of overlap identifies the differential market incentives that firms face. In this regard, focusing on changes in consumers' valuations of improvements as their requirements are satisfied and exceeded reveals how continued performance improvements may lead to a blurring of the market's underlying heterogeneity which, in turn, influences the emergence of different competitive regimes.

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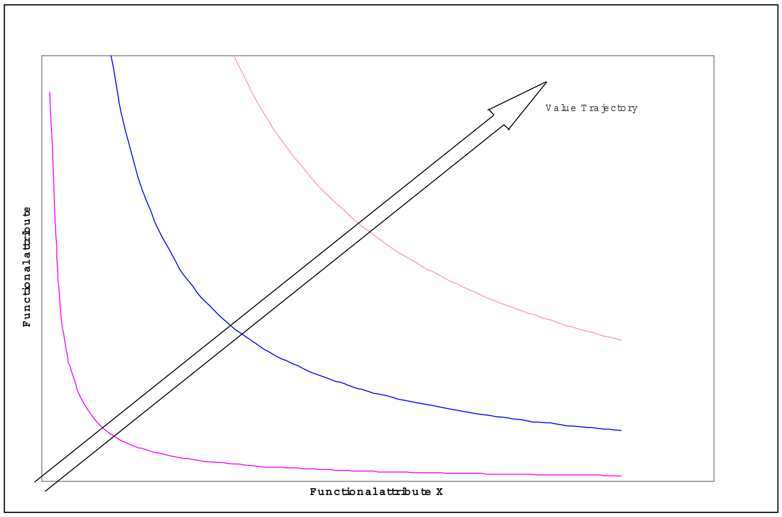

Figure 1. Indifference curves and a value trajectory.

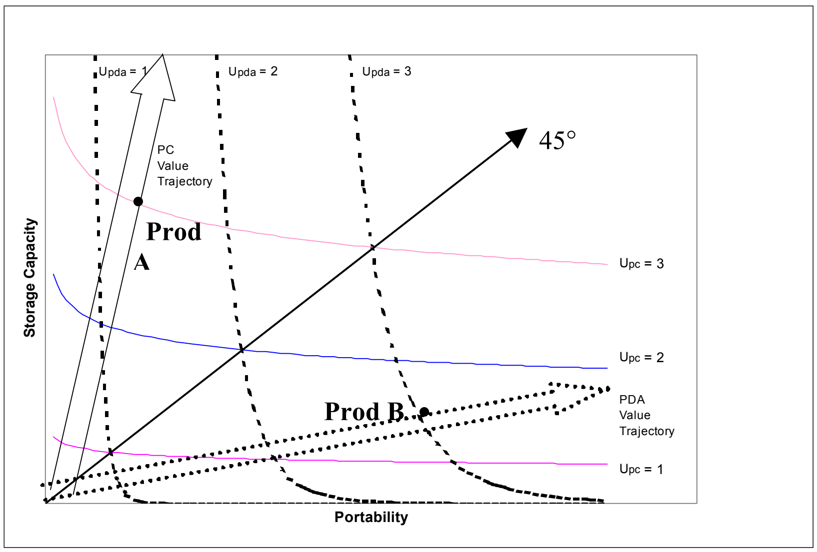

Figure 2a. Small, symmetric preferences overlap

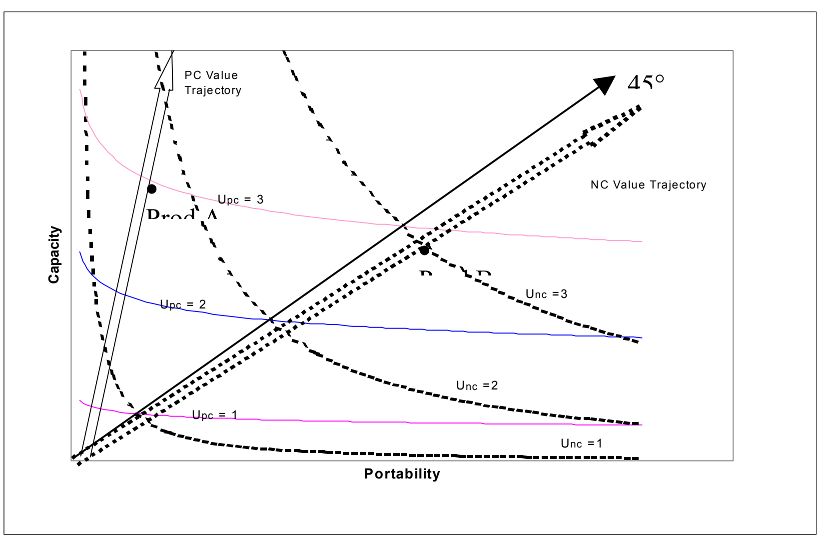

Figure 2b. Large, asymmetric preference overlap

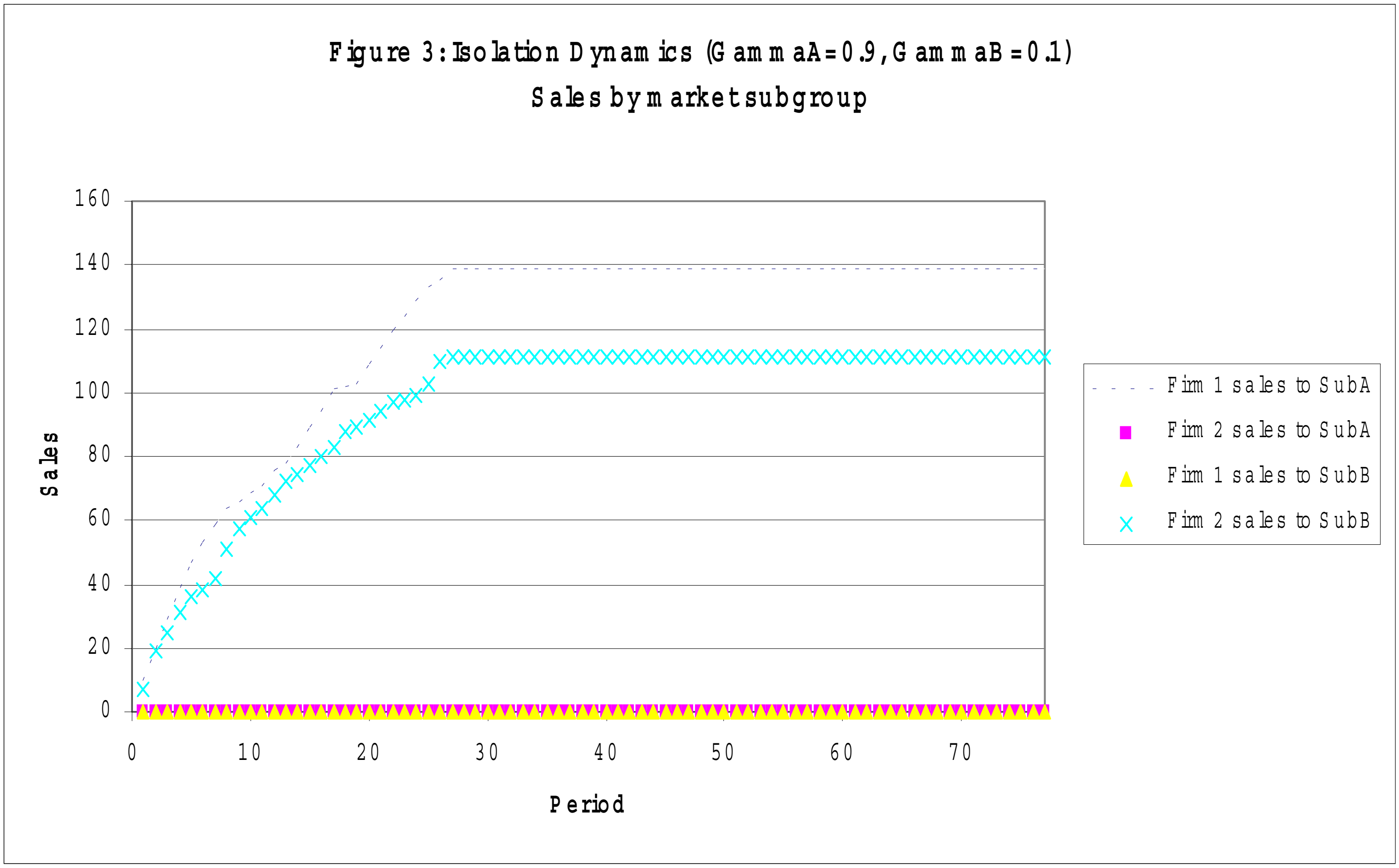
Figure 3: Isolation Dynamics (GammaA=0.9, GammaB=0.1)
Sales by market subgroup
160
140
120
100
80
60
40
20
0
Sales
0
10
20
30
40
50
60
70
Period
Firm 1 sales to SubA
Firm 2 sales to SubA
Firm 1 sales to SubB
Firm 2 sales to SubB

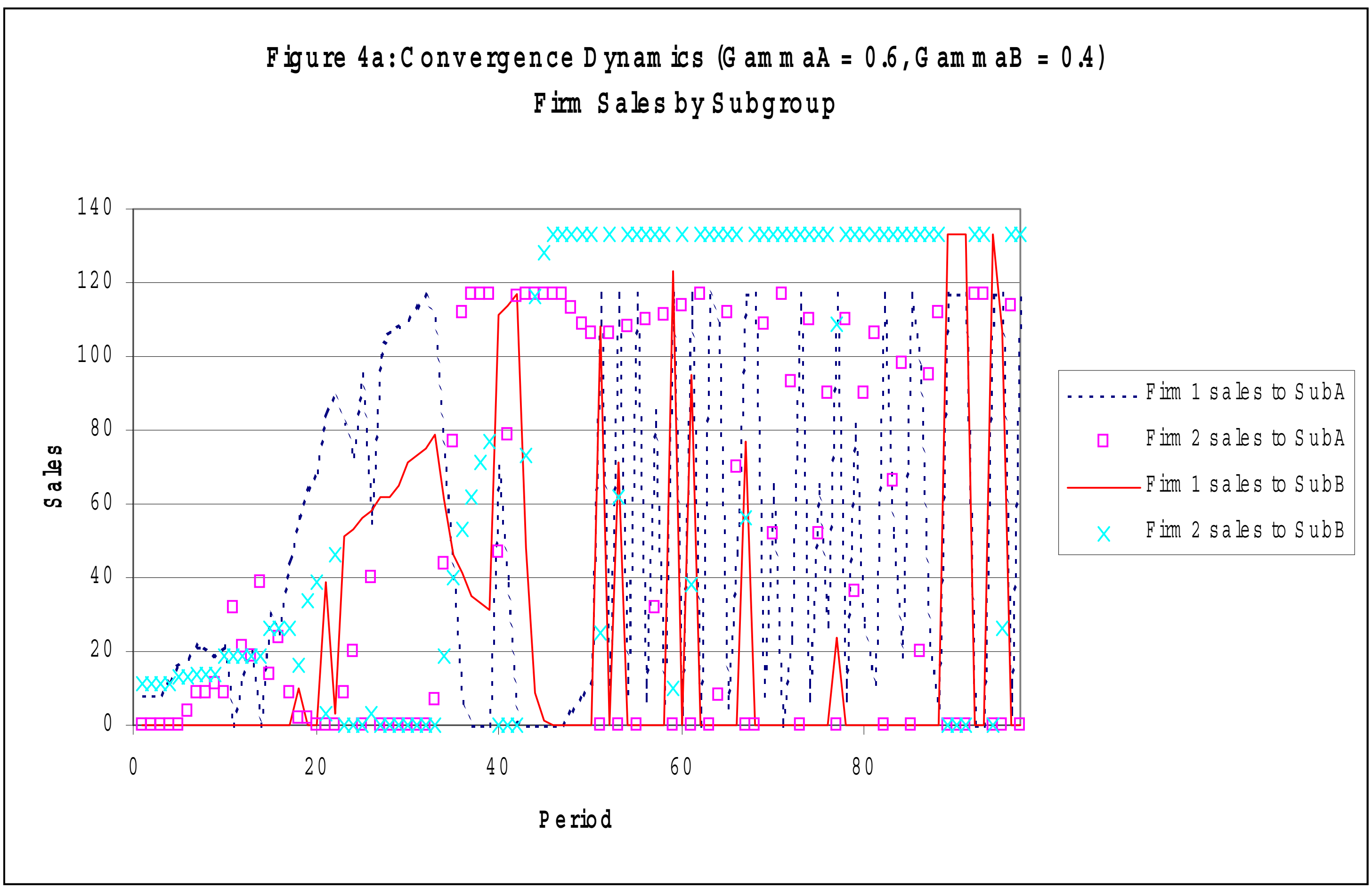
Figure 4a: Convergence Dynamics (GammaA = 0.6, GammaB = 0.4)
Firm Sales by Subgroup
140
120
100
80
60
40
20
0
Sales
0
20
40
60
80
Period
Firm 1 sales to SubA
Firm 2 sales to SubA
Firm 1 sales to SubB
Firm 2 sales to SubB

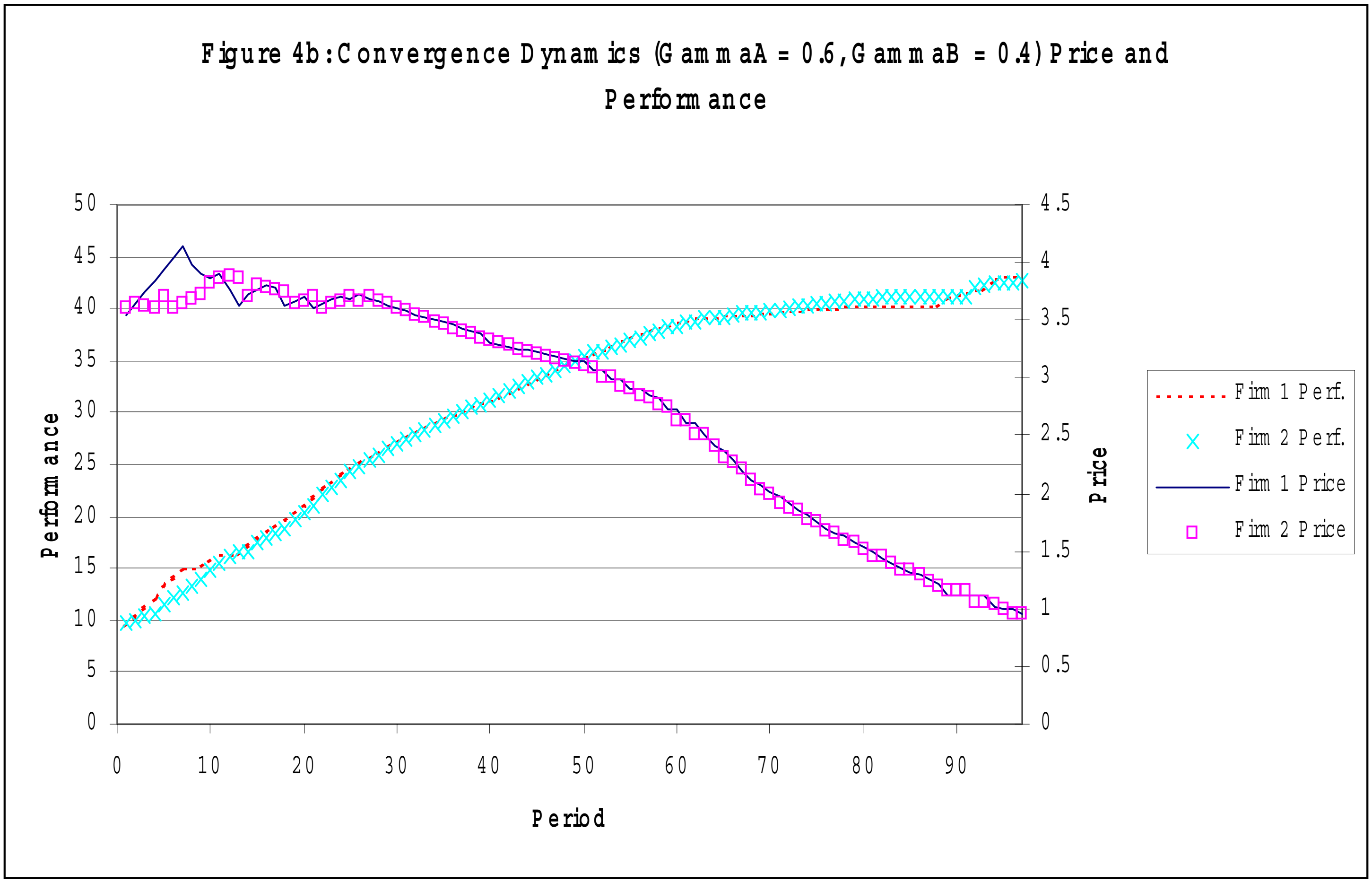
Figure 4b: Convergence Dynamics (GammaA = 0.6, GammaB = 0.4) Price and Performance
Performance
Price
Period
Firm 1 Perf.
Firm 2 Perf.
Firm 1 Price
Firm 2 Price
50
45
40
35
30
25
20
15
10
5
0
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
10
20
30
40
50
60
70
80
90

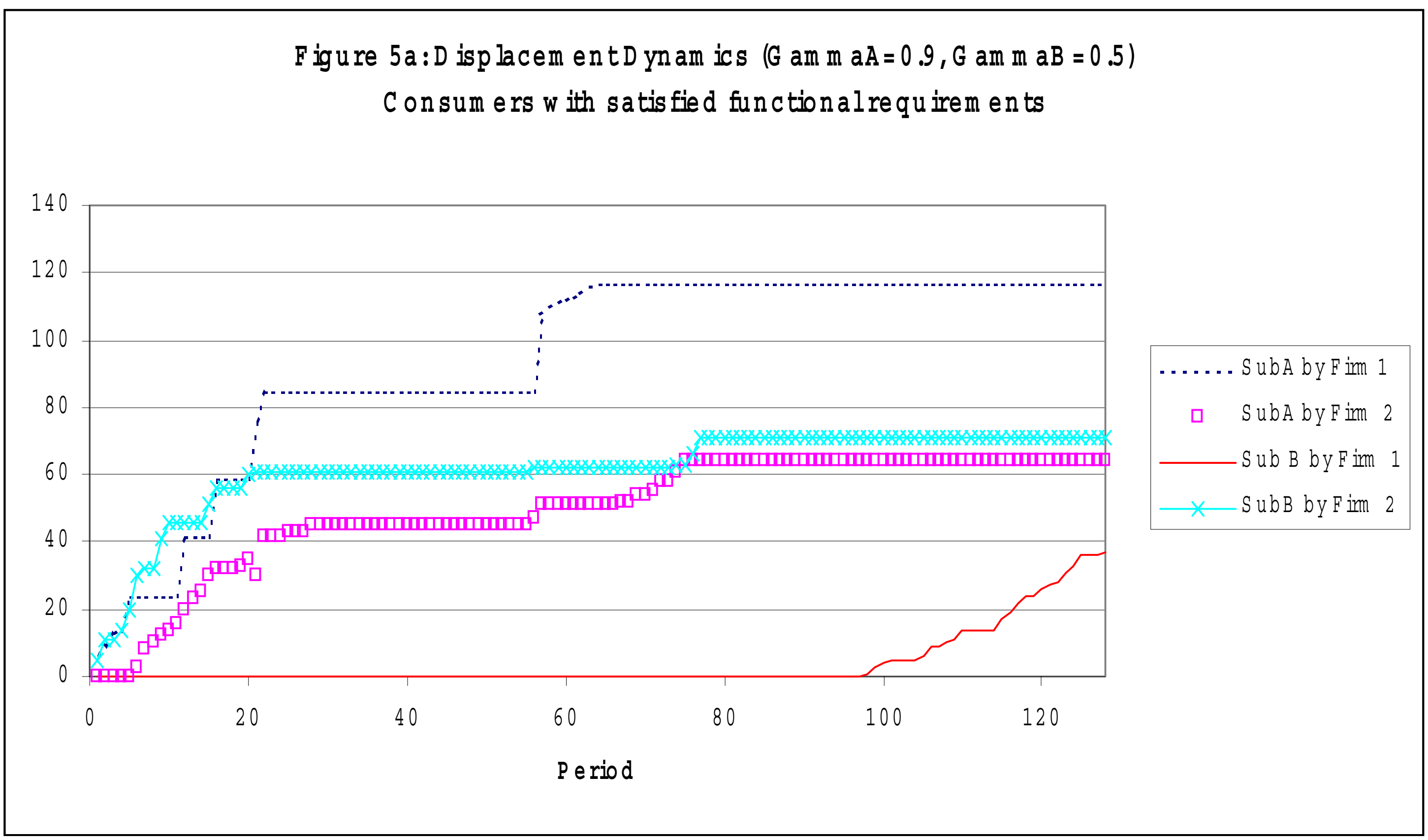
Figure 5a: Displacement Dynamics (GammaA=0.9, GammaB=0.5) Consumers with satisfied functional requirements
Period
SubA by Firm 1
SubA by Firm 2
Sub B by Firm 1
SubB by Firm 2
140
120
100
80
60
40
20
0
20
40
60
80
100
120

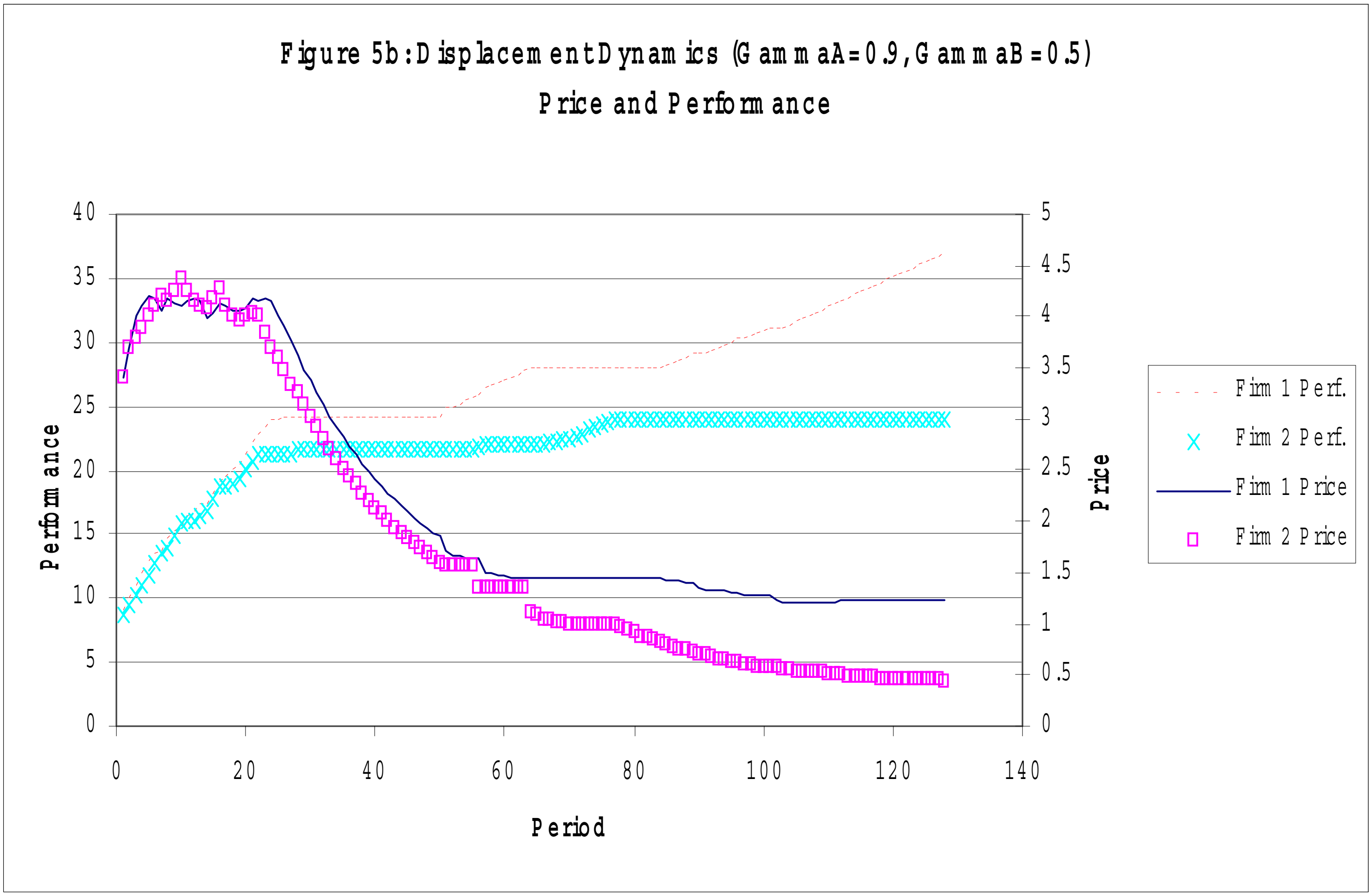
Figure 5b: Displacement Dynamics (GammaA=0.9, GammaB=0.5)
Price and Performance
Performance
Price
Period
Firm 1 Perf.
Firm 2 Perf.
Firm 1 Price
Firm 2 Price

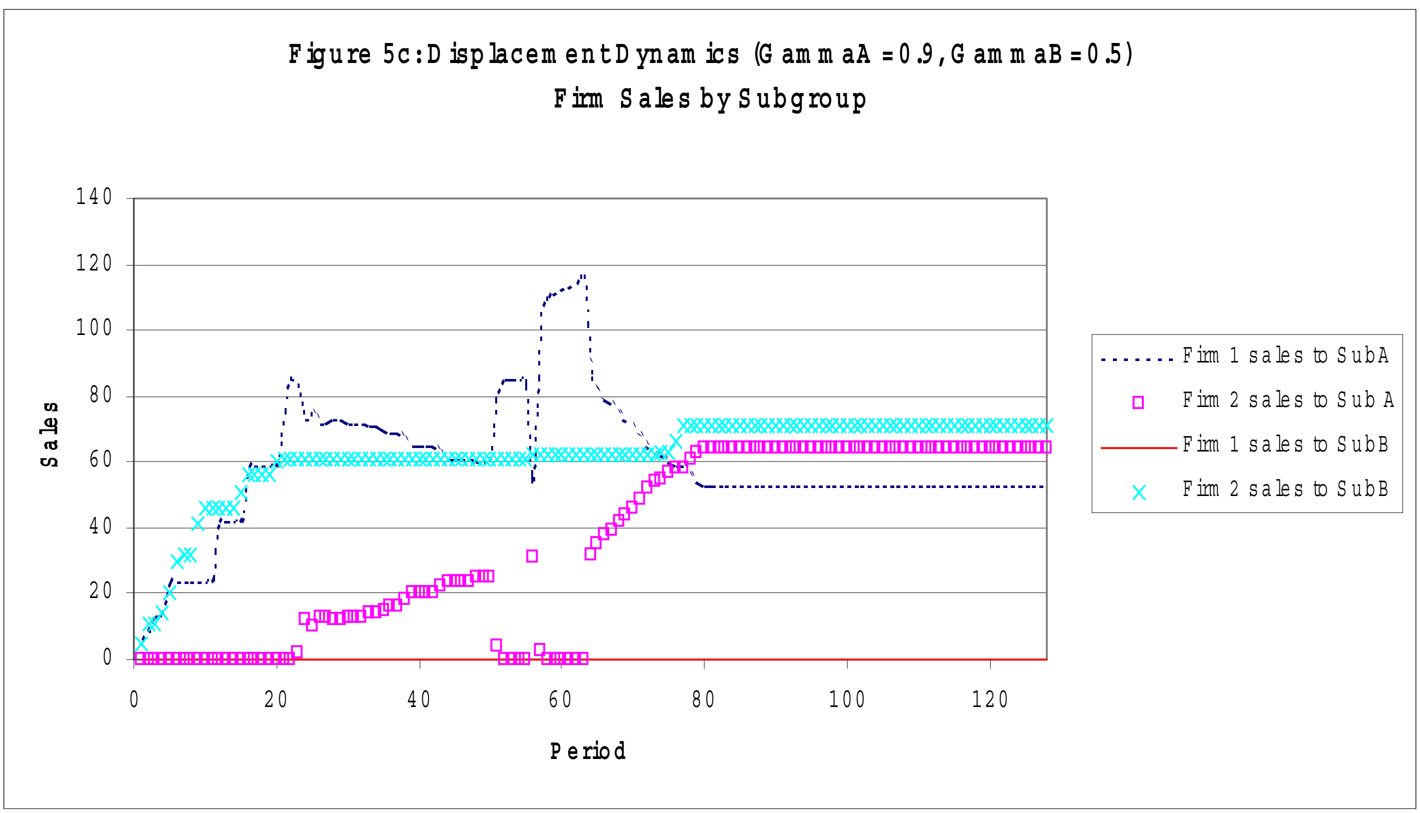
Figure 5c: Displacement Dynamics (GammaA = 0.9, GammaB = 0.5)
Firm Sales by Subgroup
Sales
Period
Firm 1 sales to SubA
Firm 2 sales to Sub A
Firm 1 sales to SubB
Firm 2 sales to SubB

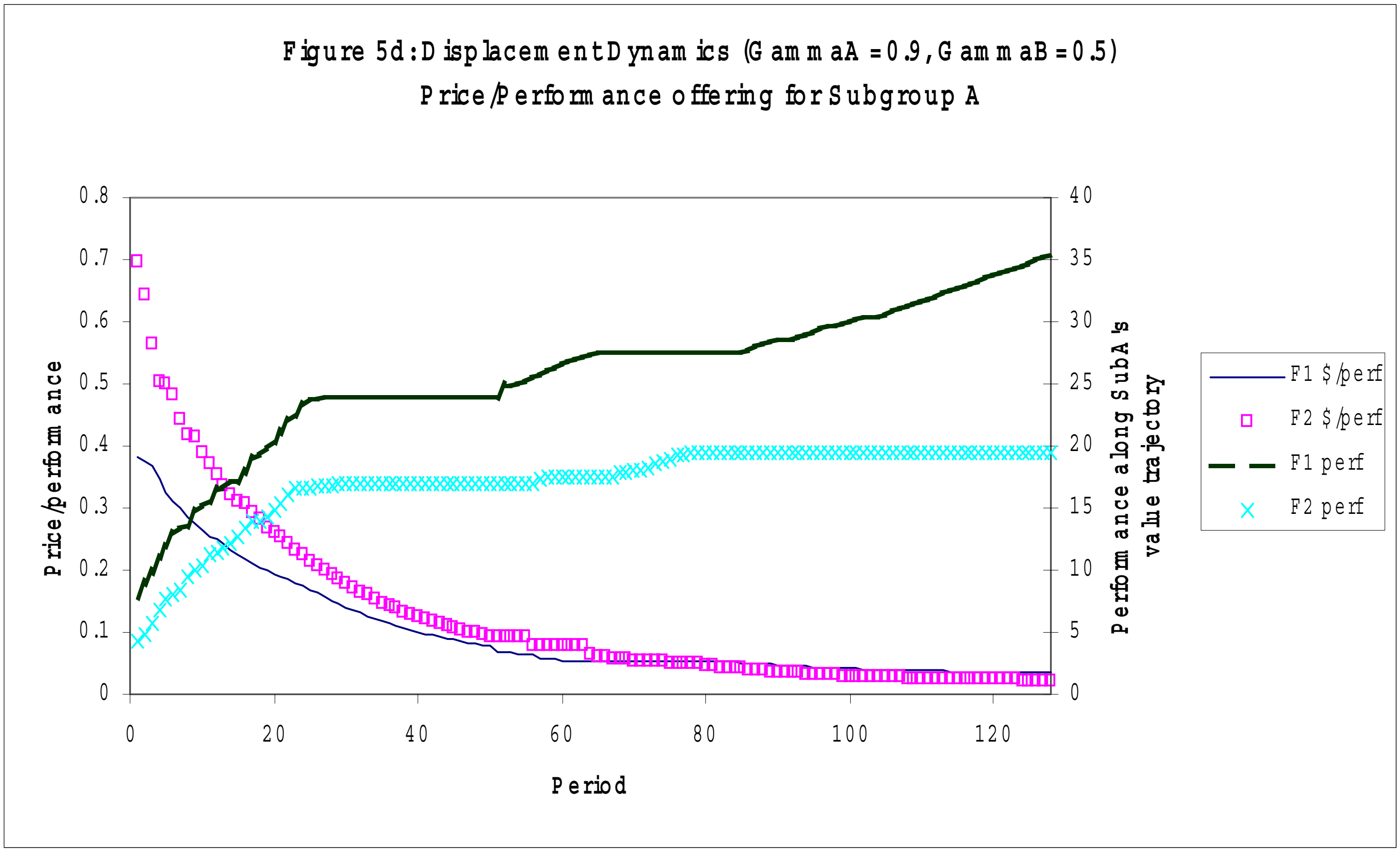
Figure 5d: Displacement Dynamics (GammaA = 0.9, GammaB = 0.5)
Price/Performance offering for Subgroup A
Price/performance
Performance along SubA's value trajectory
Period
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
F1 $/perf
F2 $/perf
F1 perf
F2 perf

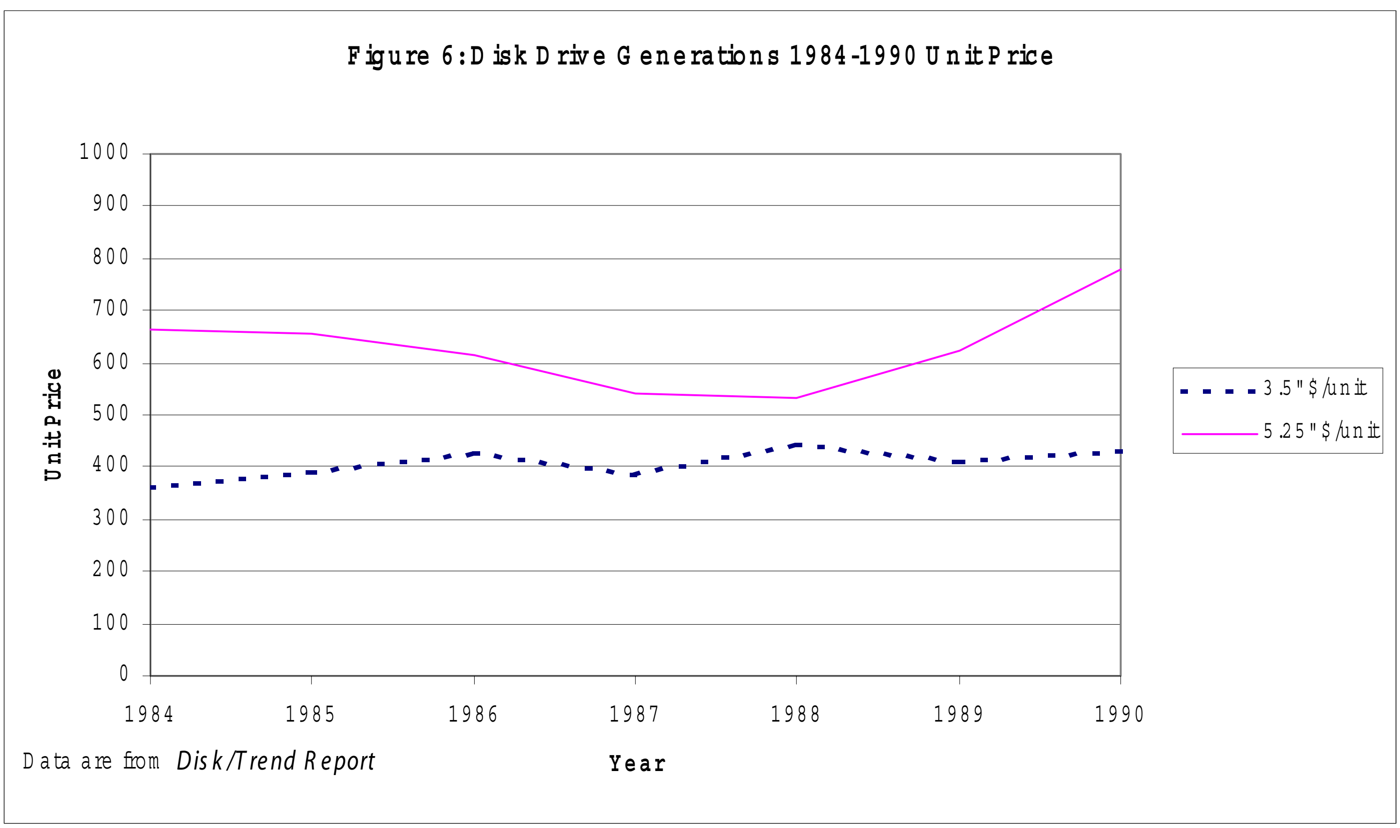
Figure 6: Disk Drive Generations 1984-1990 Unit Price
Unit Price
1000
900
800
700
600
500
400
300
200
100
0
1984
1985
1986
1987
1988
1989
1990
Year
3.5" $/unit
5.25" $/unit
Data are from *Disk/Trend Report*

Endnotes

[1] The conceptualization 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.

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

[3] I use the term market subgroup to denote consumers with similar relative preferences. While *relative preferences* are consistent within a market subgroup, *absolute requirements* for functionality and price may vary among member consumers. Market subgroup is thus different from the traditional definition of a 'market segment', which is often interpreted as a group of consumers who share *both* similar relative preferences and similar absolute requirements (e.g. high-end and low-end segments of a particular market subgroup).

[4] 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 Lancasterian 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).

[5] For purposes of expository clarity, the model will be developed using two functional dimensions, but can be extended in a straightforward manner to incorporate higher dimensional spaces.

[6] The current 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 non-systematic 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.

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

[8] Note that $[\log U]/(1-\alpha) = \alpha/(1-\alpha)\log B - \log P$. Hence our 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.

[9] Implicit in this discussion is the assumption that the distance between indifference curves is cardinal, which allows 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. (1991, p.158-9). 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 model in this essay allows, in the spirit of Lancaster's stated intent, for the explicit consideration of cardinal utilities, and such utilities are therefore used.

[10] 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 with which this essay is concerned.

[11] 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.

[12] 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. While limiting the applicability of the results, research in the management of technology suggests that this limitation is not particularly restrictive (Lynne Morone and Paulson, 1996; Cusumano, Mylonadis and Rosenbloom, 1992; Dessauer, 1972; Levinthal, 1998).

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

[14] The term *focal subgroup* refers to the market subgroup with which a firm is initially aligned.

[15] In all figures functional performance is measured as products' Euclidean distance from the origin, |**F**j|.

[16] Firm 2's price reduction ultimately provide 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.

[17] The data for Figure 6 were obtained from Disk/Trend Reports.

[18] Christensen states that incumbents have higher cost structures than entering rivals so that they need higher margins to survive. This speaks to asymmetries in, what are within the context of the model, 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 a harder time holding on to less demanding consumers and lose market share at the low end of the market. The power of the current analysis is to show that this situation can occur even without such supply side asymmetries.