Strategic Management Journal, Vol. 17, 197–218 (1996)

CUSTOMER POWER, STRATEGIC INVESTMENT, AND THE FAILURE OF LEADING FIRMS

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Why might firms be regarded as astutely managed at one point, yet subsequently lose their positions of industry leadership when faced with technological change? We present a model, grounded in a study of the world disk drive industry, that charts the process through which the demands of a firm's customers shape the allocation of resources in technological innovation—a model that links theories of resource dependence and resource allocation. We show that established firms led the industry in developing technologies of every sort—even radical ones—whenever the technologies addressed existing customers' needs. The same firms failed to develop simpler technologies that initially were only useful in emerging markets, because impetus coalesces behind, and resources are allocated to, programs targeting powerful customers. Projects targeted at technologies for which no customers yet exist languish for lack of impetus and resources. Because the rate of technical progress can exceed the performance demanded in a market, technologies which initially can only be used in emerging markets later can invade mainstream ones, carrying entrant firms to victory over established companies.

Students of management have marveled at how hard it is for firms to repeat their success when technology or markets change, for good reason: there are lots of examples. For instance, no leading computer manufacturer has been able to replicate its initial success when subsequent architectural technologies and their corresponding markets emerged. IBM created and continues to dominate the mainframe segment, but it missed by many years the emergence of the minicomputer architecture and market. The minicomputer was developed, and its market applications exploited, by firms such as Digital Equipment and Data General. While very successful in their initial markets, the minicomputer makers largely missed the advent of the desktop computer: a market which was created by entrants such as Apple, Commodore and Tandy, and only later by IBM. The engineering workstation leaders were Apollo and Sun Microsystems, both entrants to the industry. The pioneers of the portable computing market—Compaq, Zenith, Toshiba and Sharp— were not the leaders in the desktop segment.

And yet even as these firms were missing this sequence of opportunities, they were *very* aggressively and successfully leading their industries in developing and adopting many strategically important and technologically sophisticated technologies. IBM's leadership across generations of multi-chip IC packaging, and Sun Microsystems' embrace of RISC microprocessor technology, are two instances. There are many other examples, discussed below, of firms that aggressively stayed at the forefront of technology development for extended periods, but whose industry leadership was later shaken by shifting technologies and markets.

The failure of leading firms can sometimes be ascribed to managerial myopia or organizational lethargy, or to insufficient resources or expertise. For example, cotton-spinners simply lacked the human, financial and technological resources to

Key words: innovation; resource allocation; strategy change; technological change; failure

CCC 0143–2095/96/030197–22

Received 20 September 1993
Final revision received 26 May 1995

compete when DuPont brought synthetic fibers into the apparel industry. But in many instances, the firms that missed important innovations suffered none of these problems. They had their competitive antennae up; aggressively invested in new products and technologies; and listened astutely to their customers. Yet they still lost their positions of leadership. This paper examines why and under what circumstances financially strong, customer-sensitive, technologically deep and rationally managed organizations may fail to adopt critical new technologies or enter important markets—failures to innovate which have led to the decline of once-great firms.

Our conclusion is that a primary reason why such firms lose their positions of industry leadership when faced with certain types of technological change has little to do with technology itself—with its degree of newness or difficulty, relative to the skills and experience of the firm. Rather, they fail because they listen too carefully to their customers— and customers place stringent limits on the strategies firms can and cannot pursue.

The term 'technology', as used in this paper, means the processes by which an organization transforms labor, capital, materials, and information into products or services. All firms have technologies. A retailer such as Sears employs a particular 'technology' to procure, present, sell, and deliver products to its customers, while a discount warehouse retailer such as the Price Club employs a different 'technology'. Hence, our concept of technology extends beyond the engineering and manufacturing functions of the firm, encompassing a range of business processes. The term 'innovation' herein refers to a change in technology.

A fundamental premise of this paper is that patterns of resource allocation heavily influence the types of innovations at which leading firms will succeed or fail. In every organization, ideas emerge daily about new ways of doing things—new products, new applications for products, new technical approaches, and new customers—in a manner chronicled by Bower (1970) and Burgelman (1983a, 1983b). Most proposals to innovate require human and financial resources. The patterns of innovation evidenced in a company will therefore mirror to a considerable degree the patterns in how its resources are allocated to, and withheld from, competing proposals to innovate.

We observe that because effective resource allocation is market-driven, the resource allocation procedures in successful organizations provide impetus for innovations known to be demanded by current customers in existing markets. We find that established firms in a wide range of industries have tended to lead in developing and adopting such innovations. Conversely, we find that firms possessing the capacity and capability to innovate may fail when the innovation does *not* address the foreseeable needs of their current customers. When the initial price/performance characteristics of emerging technologies render them competitive only in emerging market segments, and not with current customers, resource allocation mechanisms typically deny resources to such technologies. Our research suggests that the inability of some successful firms to allocate sufficient resources to technologies that initially cannot find application in mainstream markets, but later invade them, lies at the root of the failure of many once-successful firms.

EARLIER VIEWS OF FACTORS INFLUENCING PATTERNS OF RESOURCE ALLOCATION IN THE INNOVATION PROCESS

Our research links two historically independent streams of research, both of which have contributed significantly to our understanding of innovation. The first stream is what Pfeffer and Salancik (1978) call *resource dependence*: an approach which essentially looks *outside* the firm for explanations of the patterns through which firms allocate resources to innovative activities. Scholars in this tradition contend that firms' strategic options are constrained because managerial discretion is largely a myth. In order to ensure the survival of their organizations, managers lack the power to do anything other than to allocate resources to innovative programs that are required of the firm by external customers and investors: the entities that provide the resources the firm needs to survive. Support for this view comes from the work of historians of technological innovation such as Cooper and Schendel (1976) and Foster (1986). The firms they studied generally responded to the emergence of competitively threatening technologies by intensifying their investments to improve the conventional technologies used by their current customers—which provided the resources the firms needed to survive over the short term.

The second stream of ideas, originally taught by Bower (1970) and amplified by Burgelman (1983a, 1983b), describes the resource allocation process internal to the firm. These scholars suggest that most strategic proposals—to add capacity or develop new products or processes—take their fundamental shape at lower levels of hierarchical organizations. Bower observed that the allocation of funding amongst projects is substantially shaped by the extent to which managers at middle levels of the organization decide to support, or lend *impetus*, to some proposals and to withhold it from others. Bower also observed that risk management and career management were closely linked in the resource allocation process. Because the career costs to aspiring managers of having backed an ultimately unsuccessful project can be severe, their tendency was to back those projects where the demand for the product was assured.

Our study links these two streams by showing how the impetus that drives patterns of resource allocation (and hence innovation) within firms does not stem from autonomous decisions of risk-conscious managers. Rather, whether sufficient impetus coalesces behind a proposed innovation is largely determined by the presence or absence of current customers who can capably articulate a need for the innovation in question. There seems to be a powerful linkage from: (1) the expectations and needs of a firm's most powerful customers for product improvements; to (2) the types of innovative proposals which are given or denied impetus within the firm and which therefore are allocated the resources necessary to develop the requisite technological capabilities; to (3) the markets toward which firms will and will not target these innovations; which in turn leads to (4) the firms' ultimate commercial success or failure with the new technology.

A primary conclusion of this paper is that when significant customers demand it, sufficient impetus may develop so that large, bureaucratic firms can embark upon and successfully execute technologically difficult innovations—even those that require very different competencies than they initially possessed.[1] Conversely, we find that when a proposed innovation addresses the needs of small customers in remote or emerging markets that do not supply a significant share of the resources a firm currently needs for growth and survival, firms will find it difficult to succeed even at innovations that are technologically straightforward. This is because the requisite impetus does not develop, and the proposed innovations are starved of resources.

Our findings build upon the work of earlier scholars who have addressed the question of why leading firms may fail when faced with technological change. Cooper and Schendel (1976) found that new technologies often are initially deployed in new markets, and that these were generally brought into industries by entering firms. They observed that established firms confronted with new technology often intensified investment in traditional technical approaches, and that those that did make initial resource commitments to a new technology rarely maintained adequate resource commitments. Foster (1986) noted that at points when new technologies enter an industry, entrants seem to enjoy an 'attacker's advantage' over incumbent firms. Henderson and Clark (1990) posited that entrant firms enjoyed a particular advantage over incumbents in architectural technology change.

We hope to add additional precision and insight to the work of these pioneering scholars, by stating more precisely the specific sorts of technological innovations that are likely initially to be deployed in new applications, and the sorts that are likely to be used in mainstream markets from the beginning; and to define the types of innovation in which we expect attackers to enjoy an advantage, and the instances in which we expect incumbents to hold the upper hand. By presenting a model of the processes by which resource commitments are made, we hope partially to explain a puzzle posed but not resolved by each of these authors: *why* have incumbent firms generally intensified their commitments to conventional technology, while starving efforts to commercialize new technologies—even while the new technology was gaining ground in the market?

[1] Evidence supporting this conclusion is provided below. In making this statement, we contest the conclusions of scholars such as Tushman and Anderson (1986), who have argued that incumbent firms are most threatened by attacking entrants when the innovation in question destroys, or does not build upon, the competence of the firm. We observe that established firms, though often at great cost, have led their industries in developing critical competence-destroying technologies, when the new technology was needed to meet existing customers' demands.

Finally, by examining why established firms do these things, we hope to provide insights for how managers can more successfully address different types of technological change.

RESEARCH METHODS

Three very different classes of data were used in this study, to establish solid construct validity (Yin, 1989). The first was a data base of the detailed product and performance specifications for every disk drive model announced by every firm participating in the world industry between 1975 and 1990—over 1400 product models in all. These data came from *Disk/Trend Report*, the leading market research publication in the disk drive industry, and from product specification sheets obtained from the manufacturers themselves. The tables and other summary statistics reported in this paper were calculated from this data base, unless otherwise noted. This data set is not a statistical sample, but constitutes a complete census of companies and products for the world industry during the period studied.

The second type of information employed in the study relates to the strategies pursued, and the commercial success and failure, of each of the companies that announced the development of a rigid disk drive between 1976 and 1990. *Disk/Trend* reported each firm's rigid disk drive sales in each of these years, by product category and by market segment. Each monthly issue between 1976 and 1990 of *Electronic Business* magazine, the most prominent trade publication covering the magnetic recording industry, was examined for information about disk drive manufacturers, their strategies and products. We used this information to verify the completeness of the *Disk/Trend* data,[2] and to write a history of the disk drive industry describing the strategies and fortunes of firms in the industry (Christensen, 1993).

The third type of information employed in this study came from over 70 personal, unstructured interviews conducted with executives who are or have been associated with 21 disk drive manufacturing companies. Those interviewed included founders; chief executives; vice presidents of sales and marketing, engineering and finance; and engineering, marketing and managerial members of pivotal product development project teams. The firms whose executives were interviewed together account for over 80 percent of the disk drives produced in the world since the industry's inception. Data from these interviews were used to reconstruct, as accurately as possible, the decision-making processes associated with key innovations in each company's history. Wherever possible, accounts of the same decision were obtained from multiple sources, including former employees, to minimize problems with *post hoc* rationalization. Multiple employees were interviewed in 16 of the 21 companies.

The *Disk/Trend* data enabled us to measure the impact that each new component and architectural technology had on disk drive performance. Furthermore, it was possible to identify which firms were the first to develop and adopt each new technology, and to trace the patterns of diffusion of each new technology through the world industry over time, amongst different types of firms. When analysis of the *Disk/Trend* data indicated a particular entrant or established firm had prominently led or lagged behind the industry in a particular innovation, we could determine the impact of that leadership or followership on the subsequent sales and market shares, by product-market segment, for each company.

Analysis of these data essentially enabled us to develop a theory of *what* will happen when different types of technological change occur—whether we would expect entrant and established firms to take leadership in their development. We then used our interview data to write case histories of key decisions in six companies to understand *why* those patterns of leadership and followership in technology development occur. These case studies covered entrant and established firms, over an extended period of time in which each of them made decisions to invest, or delay investing, in a variety of new technologies. These cases were selected in what Yin (1989) calls a multi-case, nested experimental design, so that through pattern-matching across cases, the external validity of the study's conclusions could be established.[3]

[2] *Disk/Trend Report* identified 133 firms that participated in the disk drive industry in the period studied. The search of *Electronic Business* magazine yielded information on one additional firm, Peach Tree Technology, that never generated revenues and somehow had escaped detection by the *Disk/Trend* editors.

[3] Table 3 (which refers to Yin, 1989: 35–37) describes this pattern-matching.

We studied the disk drive industry because its history is one of rapid change in technology and market structure. The world rigid disk drive market grew at a 27 percent annual rate to over $13 billion between 1975 and 1990. Of the 17 firms in the OEM industry in 1976, only one was still in operation in 1990. Over 130 firms entered the industry during this period, and more than 100 of them failed. The cost per megabyte (MB) of the average drive in constant 1990 dollars fell from $560 in 1976 to $5 in 1990. The physical size of a 100 MB drive shrank from 5400 to 8 cubic inches over the same period. During this time, six architecturally distinct product generations emerged, and a new company rose to become market leader in four of these six generations. A description of disk drive technology that may be helpful for some readers is provided in Appendix 1.

TYPOLOGIES OF TECHNOLOGICAL CHANGE

Earlier scholars of technology change have argued that incumbent firms may stumble when technological change destroys the value of established technological competencies (Tushman and Anderson, 1986), or when new architectural technologies emerge (Henderson and Clark, 1990). For present purposes, however, we have found it useful to distinguish between those innovations that *sustained* the industry's rate of improvement in product performance (total capacity and recording density were the two most common measures), and those innovations that *disrupted* or redefined that performance trajectory (Dosi, 1982). The following two sections illustrate these concepts by describing prominent examples of trajectory-sustaining and trajectory-disrupting technological changes in the industry's history. The subsequent sections then describe the role these innovations played in the industry's development; the processes through which incumbent and entrant firms responded to these different types of technological change; and the consequent successes and failures these firms experienced.

Sustaining technological changes

In the disk drive industry's history, most of the changes in competent technology, and two of the six changes in architectural technology, sustained or reinforced established trajectories of product performance improvement. Two examples of such technology change are shown in Figure 1. The left-most graph compares the average recording density of drives that employed conventional particulate oxide disk technology and ferrite head technology, vs. the average density of drives that employed new-technology thin film heads and disks, that were introduced in each of the years between 1976 and 1990. The improvements in the conventional approach are the result of consistent incremental advances such as grinding the ferrite heads to finer, more precise dimensions; and using smaller and more finely dispersed oxide particles on the disk's surface. Note that the improvement in areal density obtainable with ferrite/oxide technology began to level off in the period's later years—suggesting a maturing technology S-curve (Foster, 1986). Note how thin film head and disk technologies emerged to sustain the rate of performance improvement at its historical pace of 35 percent between 1984 and 1990.

The right-most graph in Figure 1 describes a sustaining technological change of a very different character: an innovation in product architecture. In this case, the 14-inch Winchester drive substituted for removable disk packs, which had been the dominant design between 1962 and 1978. Just as in the thin film-for-ferrite/oxide substitution, the impact of Winchester technology was to sustain the historically established rate of performance improvement. Other important innovations, such as embedded servo systems, RLL & PRML recording codes, higher RPM motors and embedded SCSI, SMD, ESDI and AT interfaces, also helped manufacturers sustain the rate of historical performance improvement that their customers had come to expect.[4] Hereafter in this

[4] The examples of technology change presented in Figures 1 and 2 in this paper introduce some ambiguity to the unqualified term 'discontinuity', as it has been used by Dosi (1982), Tushman and Anderson (1986), and others. The innovations in head and disk technology described in the left graph of Figure 1 represent *positive discontinuities* in an established technological trajectory, while the development of trajectory-disrupting technologies charted in Figure 2 represent *negative* discontinuities. As will be shown below, established firms seemed quite capable of leading the industry over positive discontinuities. The negative ones were the points at which established firms generally lost their positions of industry leadership.

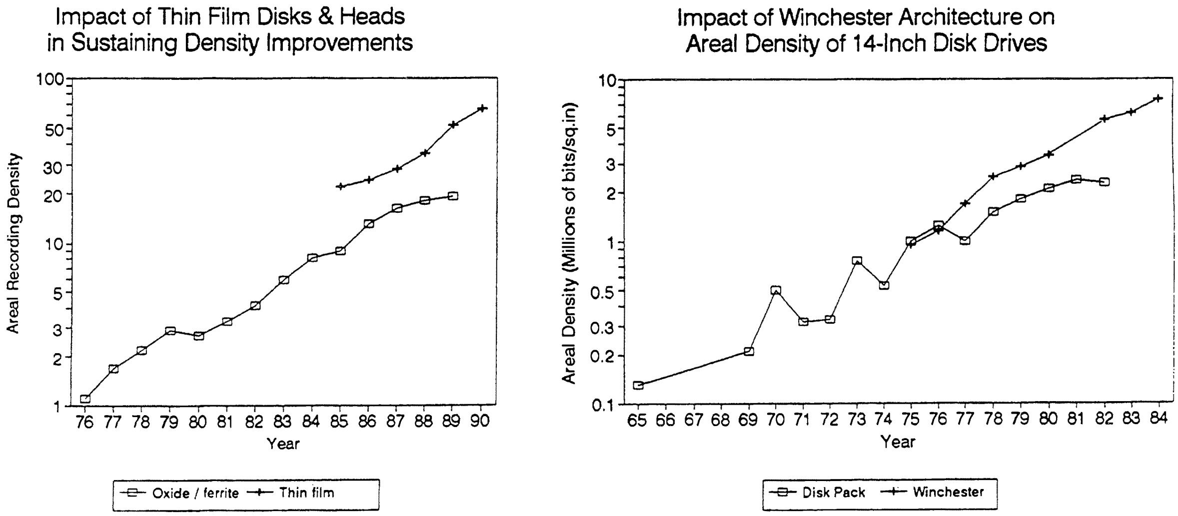

Figure 1. Examples of sustaining technological change in componentry (left) and product architecture (right). Reprinted with permission from *Business History Review*, 1993, **67**, p. 557.

paper, technological changes that have such a sustaining impact on an established trajectory of performance improvement are called *sustaining technologies*.

Disruptive technological changes

Most technological change in the industry's history consisted of sustaining innovations of the sort described above. In contrast, there were just a few trajectory-disrupting changes. The most important of these from a historical viewpoint were the architectural innovations that carried the industry from 14-inch diameter disks to diameters of 8, 5.25 and then 3.5 inches. The ways in which these innovations were disruptive are illustrated in Table 1. Set in 1981, this table compares the attributes of a typical 5.25-inch drive—a new architecture that had been in the market for less than a year at that time—with those of a typical 8-inch drive, which by that time had become the standard drive used by minicomputer manufacturers. Note that along the dimensions of performance which were important to established minicomputer manufacturers—capacity, cost per megabyte, and access time—the 8-inch product was vastly superior. The 5.25-inch architecture did not address the needs of minicomputer manufacturers, as they perceived their needs at that time. On the other hand, the 5.25-inch architecture *did* possess attributes that appealed to the desktop personal computer market segment that was just emerging in 1980–82. It was small and lightweight—important features for this application. And it was priced at around $2000, which means it could economically be incorporated in desktop machines. Hereafter in this paper, technologies such as this, which disrupt an established trajectory of performance improvement, or redefine what performance means, are called *disruptive technologies*.

In general, sustaining technological changes appealed to established customers in existing, mainstream markets. They provided these customers with more of what they had come to

Table 1. The disruptive impact on performance improvement of the 5.25-inch, vs. the 8-inch architecture

Attribute	8-inch drives	5.25-inch drives
Capacity (megabytes)	**60**	10
Volume (cubic inches)	566	*150*
Weight (pounds)	21	*6*
Access time (ms)	**30**	160
Cost per megabyte	**$50**	$200
Total unit cost	$3000	*$2000*

Key: Attributes valued highly in the minicomputer market in 1981 are presented in **boldface**.
Attributes valued in the emerging desktop computing market in 1981 are shown in *italics*.
Source: Analysis of Disk/Trend Report data; from Christensen (1992a: 90).

expect. In contrast, disruptive technologies rarely could initially be employed in established markets. They tended instead to be valued in remote or emerging markets. This tendency consistently appears not just in disk drives, but across a range of industries (Rosenbloom and Christensen, 1995).

THE IMPACT OF SUSTAINING AND DISRUPTIVE TECHNOLOGIES ON INDUSTRY STRUCTURE

The history of sustaining and disruptive technological change in the disk drive industry is summarized in Figure 2. It begins in 1974, the year after IBM's first Winchester architecture model was introduced to challenge the dominant disk pack architectural design. Almost all drives then were sold to makers of mainframe computers. Note that in 1974 the median-priced mainframe computer was equipped with about 130 MB of hard disk capacity. The typical hard disk storage capacity supplied with the median-priced mainframe increased about 17 percent per year, so that by 1990 the typical mainframe was equipped with 1300 MB of hard disk capacity. This growth in the use of hard disk memory per computer is mapped by the solid line emanating from point A in Figure 2. This trajectory was driven by user learning and software developments in the applications in which mainframes were used (Christensen and Rosenbloom, 1995).

The dashed line originating at point A measures the increase in the average capacity of 14-inch drives over the same period. Note that although the capacity of the average 14-inch drive was equal to the capacity shipped with the typical mainframe in 1974, the rate of increase in capacity provided within the 14-inch architecture exceeded the rate of increase in capacity demanded in the mainframe market—carrying this architecture toward high-end mainframes, scientific computers, and supercomputers. Furthermore, note how the new 14-inch Winchester architecture sustained the capacity trajectory that had been established in the earlier removable disk pack architecture. Appendix 2 describes how these trajectories were calculated.

The solid trajectories emanating from points B, C and D represent the average hard disk capacity *demanded* by computer buyers in each market segment, over time.[5] The dashed lines emanating from points B, C, and D in Figure 2 measure trends in the average capacity that disk drive manufacturers were able to *provide* with each successive disk drive architecture. Note that with the exception of the 14-inch Winchester architecture, the maximum capacity initially available in each of these architectures was substantially *less* than the capacity required for the typical computer in the established market—these were *disruptive* innovations. As a consequence, the 8, 5.25 and 3.5-inch designs initially were rejected by the leading, established computer manufacturers, and were deployed instead in emerging market applications for disk drives: minicomputers, desktop PCs and portable PCs, respectively. Note, however, that once these disruptive architectures became established in their new markets, the accumulation of hundreds of sustaining innovations pushed each architecture's performance ahead along very steep, and roughly parallel, trajectories.[6]

Note that the trajectory of improvement that the technology was able to *provide* within each architecture was nearly *double* the slope of the increase in capacity *demanded* in each market. As we will see, this disparity between what the technology could provide and what the market demanded seems to have been the primary source of leadership instability in the disk drive industry.

LEADERS IN SUSTAINING AND DISRUPTIVE TECHNOLOGICAL INNOVATIONS

To better understand why leading firms might successfully pioneer in the development and adoption of many new and difficult technologies, and yet lose their positions of industry leadership by failing to implement others, we compared the innovative behavior of *established* firms with that of *entrant* firms, with respect to each of the

[5] These trajectories represent the disk capacity *demanded* in each market because in each instance, greater disk capacity could have been supplied to users by the computer manufacturers, had the market demanded additional capacity at the cost for which it could be purchased at the time.

[6] The parallel impact of sustaining innovations across these architectural generations results from the fact that the same sustaining technologies, in the form of componentry, were available simultaneously to manufacturers of each generation of disk drives (Christensen, 1992b).

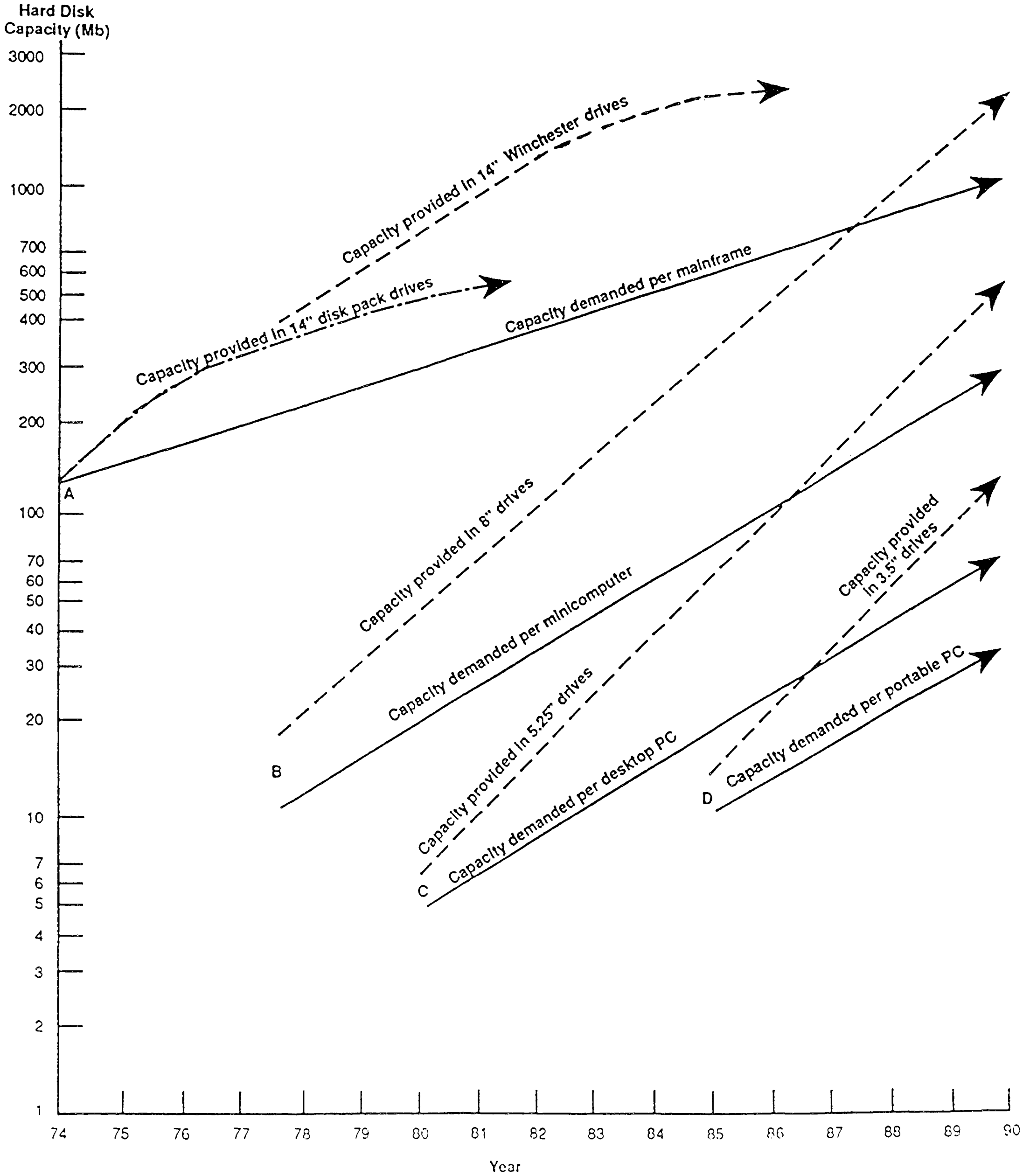

Figure 2. Patterns of entry and improvement in disruptive disk drive technologies. Reprinted with permission from *Business History Review*, 1993, **67**, p. 559.

sustaining and disruptive technological innovations in the history of the disk drive industry. Building upon the approach employed by Henderson and Clark (1990), established firms were defined as firms that had previously manufactured drives which employed an older, established technology, whereas entrant firms were those whose initial product upon entry into the industry employed the new component or architectural technology being analyzed. This approach was used because of this study's longitudinal character, looking at the performance of incumbents and entrants across a sequence of innovations.

In spite of the wide variety in the magnitudes and types of sustaining technological changes in the industry's history, the firms that led in their development and adoption were the industry's leading, established firms. Table 2(a) depicts this leadership pattern for three representative sustaining technologies. In thin-film head technology, it was Burroughs (1976), IBM (1979), and other established firms that first successfully incorporated thin-film heads in disk drives. In the 1981–86 period, when over 60 firms entered the rigid disk drive industry, only five of them (all commercial failures) attempted to do so using thin-film heads as a source of performance advantage in their initial products. All other entrant firms—even aggressively performance-oriented firms such as Maxtor and Conner Peripherals—found it preferable to cut their teeth on ferrite heads in the entry products, before tackling thin-film technology in subsequent generations.

Note the similar pattern in the development and adoption of RLL codes—a much simpler development than thin-film head technology—which consumed at most a few million dollars per firm. RLL enabled a 30 percent density improvement, and therefore represented the type of inexpensive path to performance improvement that ought to be attractive to entrant firms. But in 1985, 11 of the 13 firms which introduced new models employing RLL technology were established firms, meaning that they had previously offered models based on MFM technology. Only two were entrants, meaning that their initial products employed RLL codes. Table 2(a) also notes that six of the first seven firms to introduce Winchester architecture drives were established makers of drives employing the prior disk pack architecture.[7]

The history of literally every other sustaining innovation—such as embedded servo systems, zone-specific recording densities, higher RPM motors and the 2.5-inch Winchester architecture—reveals a similar pattern: the established firms led in the adoption of sustaining technology be it in componentry or architecture. Entrant firms followed. In other words, the failure of leading firms to stay atop the disk drive industry generally was not because they could not keep pace with the industry's movement along the dashed-line technological trajectories mapped in Figure 2. The leading incumbent firms effectively *led* the industry along those trajectories even though many of these were competency-destroying progressions in terms of technologies, skills and manufacturing assets required (Tushman and Anderson, 1986).

In contrast, the firms that led the industry in introducing *disruptive* architectural technologies—in the moves to points B, C and D in Figure 2—tended overwhelmingly to be *entrant*, rather than established firms. This is illustrated in Table 2(b). It shows, for example, that in 1978 an entrant offered the industry's first 8-inch drive. By the end of the second year of that architecture's life (1979), six firms were offering 8-inch drives; two-thirds of them were entrants. Likewise, by the end of the second year of the 5.25-inch generation's life, eight of the 10 firms offering 5.25-inch drives were entrants. Entrants similarly dominated the early population of firms offering 3.5-inch drives. In each of these generations, between half and two-thirds of the established manufacturers of the prior architectural generation *never* introduced a model in the new architecture. And those established drivemakers that did design and manufacture new architecture models did so with an average two-year lag behind the pioneering entrant firms. In this fast-paced industry, such slow response often proved fatal.

These patterns of leadership and followership in sustaining and disruptive technologies are reflected in the commercial success and failure of disk drive manufacturers. The ability of established firms to lead the industry in the sustaining innovations that powered the steep technological trajectories in Figure 2 often were technologically difficult, risky and expensive. Yet in the history of this industry, there is no evidence that the firms that led in sustaining innovations gained market share by virtue of such technology leadership (Christensen, 1992b). This leadership enabled them to maintain their competitiveness only within specific technological trajectories. On the other hand, entrant firms' leadership advantages in disruptive innovations enabled them not only to capture new markets as they emerged, but (because the trajectories of technological progress were steeper than the trajectories of performance demanded) to invade and capture established markets as well.

Hence, all but one of the makers of 14-inch drives were driven from the mainframe computer market by entrant firms that got their start making

[7] Note that the statistics shown in Table 2 are not a sample—they represent the entire population of firms in each of the years shown offering models incorporating the technologies in question. For that reason, tests of statistical significance are not relevant in this case.

Table 2. Trends in technology leadership and followership in sustaining vs. disruptive technologies

(a) Numbers of established and entrant firms introducing models employing selected trajectory-sustaining technologies

		1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Thin-film	Entrants								1		1	2	1		1	4
heads	Established			1			1	1	3	5	6	8	12	15	17	22
RLL codes	Entrants											1	2	3	6	8
	Established											4	11	20	25	26
Winchester	Entrants				1	4	9									
architecture	Established	1		3	3	7	11									

(b) Numbers of established and entrant firms introducing models based upon disruptive architectural technologies

		1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
8-inch	Entrants					1	4	6	8							
	Established					0	2	5	5							
5.25-inch	Entrants							1	8	8	13					
	Established							1	2	8	11					
3.5-inch	Entrants											1	2	3	4	
	Established											0	1	1	4	

Note: Data are presented in these tables only for those years in which the new technologies were gaining widespread acceptance, to illustrate tendencies in technology leadership and followership. Once the technologies had become broadly accepted, the numbers of firms introducing models using them are no longer reported. Twelve years are covered in the thin-film head category because it took that long for thin film heads to become broadly used in the marketplace. Only 5 years of history are reported for RLL codes because by 1988 the vast majority of established *and* entrant firms had adopted RLL codes. Four years of data are shown for new architectures, because any established firms that had not launched the new architecture within 4 years of its initial appearance in the market had been driven from the industry.

8-inch drives for minicomputers. The 8-inch drivemakers, in turn, were driven from the minicomputer market, and eventually the mainframe market, by firms which led in producing 5.25-inch drives for desktop computers. And the leading makers of 5.25-inch drives were driven from desktop and minicomputer applications by makers of 3.5-inch drives, as mapped in Figure 2.

We began this paper by posing a puzzle: why it was that firms which at one point could be esteemed as aggressive, innovative, customer-sensitive organizations could ignore or attend belatedly to technological innovations with enormous strategic importance. In the context of the preceding analysis of the disk drive industry, this question can be sharpened considerably. The established firms were, in fact, aggressive, innovative, and customer-sensitive in their approaches to sustaining innovations of every sort. But why was it that established firms could not lead their industry in disruptive architectural innovations? For it is only in these innovations that attackers demonstrated an advantage. And unfortunately for the leading established firms, this advantage enabled attacking entrant firms to topple the incumbent industry leaders each time a disruptive technology emerged.[8]

To understand why disruptive technological change was so consistently vexing to incumbent firms, we personally interviewed managers who played key roles in the industry's leading firms, as incumbents or entrants, when each of these disruptive technologies emerged. Our objective in these interviews was to reconstruct, as accurately and from as many points of view as possible, the forces that influenced these firms' decision-making processes relating to the development and commercialization of disruptive architectural technologies. We found the experiences of the firms, and the forces influencing their decisions, to be

[8] We believe this insight—that attacking firms have an advantage in disruptive innovations but not in sustaining ones—clarifies but is not in conflict with Foster's (1986) assertions about the attacker's advantage. The historical examples Foster uses to substantiate his theory generally seem to have been disruptive innovations.

remarkably similar. In each instance, when confronted with disruptive technology change, developing the requisite *technology* was never a problem: prototypes of the new drives often had been developed before management was asked to make a decision. It was in the process of allocating scarce resources amongst competing product and technology development proposals, however, that disruptive projects got stalled. Programs addressing the needs of the firms' most powerful customers almost *always* pre-empted resources from the disruptive technologies, whose markets tended to be small and where customers' needs were poorly defined.

In the following section we have synthesized the data from case studies of the six firms we studied in particular depth, into a *six*-step model that describes the factors that influenced how resources were allocated across competing proposals to develop new sustaining vs. disruptive technology in these firms. The struggle of Seagate Technology, the industry's dominant maker of 5.25-inch drives, to successfully commercialize the disruptive 3.5-inch drive, is recounted here to illustrate each of the steps in the model. Short excerpts from a fuller report of other case histories (Christensen, 1992a) are also presented to illustrate what happened in specific companies at each point in the process. Table 3 describes how the findings from each of the case studies support, or do not support, the principal propositions in the model. In Yin's (1989) terms, the high degree of literal and theoretical replication shown in Table 3, and the extent of 'pattern matching' across case studies where more than one firm encountered the same technological change, lend high degrees of reliability and external validity to the model.[9]

A MODEL OF THE RESOURCE-ALLOCATION PROCESS IN ESTABLISHED FIRMS FACED WITH DISRUPTIVE CHANGE

1. Although entrants were the leaders in *commercializing* disruptive technology, it did not start out that way: the first engineers to develop the disruptive architectures generally did so while employed by a leading established firm, using bootlegged resources. Their work was rarely initiated by senior management. While architecturally innovative, these designs almost always employed off-the-shelf components. For example, engineers at Seagate Technology, the leading 5.25-inch drive maker, were the second in the industry to develop working prototype 3.5-inch models, in 1985. They made over 80 prototype models before the issue of formal project approval was raised with senior management. The same thing happened earlier at Control Data, the dominant 14-inch drivemaker. Its engineers had designed working 8-inch drives internally, nearly 2 years before they appeared in the market.
2. The marketing organization then used its habitual procedure for testing the market appeal of new drives, by showing prototypes to lead customers of the existing product line, asking them to evaluate the new models.[10] Again drawing on the Seagate case, marketers tested the new 3.5-inch drives with IBM and other makers of XT and AT-class desktop personal computers—even though the drives, as shown in Figure 2 above, had significantly less capacity than in the mainstream desktop market demanded.

[9] For readers who are unfamiliar with the work of scholars such as Yin (1989) and Campbell and Stanley (1966) on research methodology, a *literal* replication of a model occurs when an outcome happens as the model would predict. A *theoretical* replication of the model occurs when a different outcome happens than what would have been predicted by the model, but where this outcome can be explained by elements in the model. In the instance here, the success of entrants and the failure of established forms at points of disruptive technology change are directly predicted by the model, and would be classed as literal replications. Instances where an established firm succeeded in the face of disruptive technological change because it acted in a way that dealt with the factors in the model that typically precipitated failure, would be classed as *theoretical* replications of the model. Several of these instances occurred in the industry's history, as explained later in this paper.

[10] This is consistent with Burgelman's observation that one of the greatest difficulties encountered by corporate entrepreneurs was finding the right 'beta test sites', where products could be interactively developed and refined with customers. Generally, the entre to the customer was provided by the salesman who sold the firm's established product lines. This helped the firm develop new products for established markets, but did not help it identify new applications for its new technology (Burgelman and Sayles, 1986: 76–80). Professor Rebecca Henderson pointed out to us that this tendency always to take new technologies to mainstream customers reflects a rather narrow *marketing* competence—that although these issues tend to be framed by many scholars as issues of technological competence, a firm's disabilities in finding new markets for new technologies may be its most serious innovative handicap.

Table 3. Support of key elements of model found in each of six in-depth case studies

Companies Studied:	Prototypes of disruptive architecture drive developed internally, well before widespread industry adoption (model step 1)	Marketers show early prototypes to lead customers of prior architecture; they reject product; marketing issues pessimistic forecast (model step 2)	Project to commercialize disruptive product is shelved; company aggressively pursues sustaining innovations (model step 3)	New firms are established to commercialize disruptive architecture; they find new markets, where product's attributes are valued (model step 4)	Entrant firms which initially sold product only in new market improve performance faster than initial market requires, enabling them to attack established markets (model step 5)	In response to entrants' attack, established firms belatedly introduce disruptive product. Sales are largely to existing customers, cannibalizing sales of prior architecture products. (model step 6)
Quantum Corp.	L	L	L, T	L, T	L	L, T
Conner Peripherals	L		L	L	L	
Miniscribe		L		L	L	L
Seagate Technology	L	L	L	L	L	L
Micropolis	T	L	L,T	L,T	L	T
Control Data	L	L	L,T	L,T	L	L,T

Note: An 'L' in the matrix indicates that this step was a clear, explicit element in that firm's case history—in Yin's (1989) terms, a 'literal replication'. Where 'T' is shown, the firm avoided the fate described in the model by explicitly recognizing the factors in the model, and dealing with them in the manner described in the final section of this paper. These constitute what Yin calls 'theoretical replications' of the model. Where no 'L' or 'T' is shown, that step was not a clear or prominent part of the firm's encounter with the disruptive technology being studied. Some firms studied confronted only one disruptive architecture. Miniscribe, for example, started making 5.25-inch drives generally in the pattern indicated by our model; and was subsequently driven from the industry. Other firms, such as Quantum and Control Data, confronted a series of disruptive innovations, and dealt with some of them differently than they did with others, as described in the last section of the paper. In such instances, an 'L' and a 'T' are entered in the matrix. As Yin points out, when multiple case studies are used to support a multi-element model, as in this study, each cell in a matrix such as this constitutes an independent 'observation'. Hence, the model is supported in 32 of the 36 observations.

These customers showed little interest in the disruptive drives, because they did not address their need for higher performance within the established architectural framework. As Figure 2 shows, the established customers needed new drives that would take them *along* their existing performance trajectory. As a consequence, the marketing managers were unwilling to support the disruptive technology and offered pessimistic sales forecasts.

Generally, because the disruptive drives were targeted at emerging markets, initial forecasts of sales were small. In addition, because such products were simpler and offered lower performance, forecast profit margins were also lower than established firms had come to require. Financial analysts in established firms, therefore, joined their marketing colleagues in opposing the disruptive programs. As a result, in the ensuing allocation process resources were explicitly withdrawn, and the disruptive projects were slowly starved.

For example, when Seagate's main customer, IBM's PC division, rejected Seagate's 3.5-inch prototypes for insufficient capacity, sales forecasts were cut and senior managers shelved the program—just as 3.5-inch drives were becoming firmly established in laptops. 'We needed a new model,' recalled a former Seagate manager, 'which could become the next ST412 (a very successful product generating $300 million sales annually in the desktop market that was near the end of its life cycle). Our forecasts for the 3.5-inch drive were under $50 million because the laptop market was just emerging—and the 3.5-inch product just didn't fit the bill.' And earlier, when engineers at Control Data, the leading 14-inch drive maker, developed its initial 8-inch drives, its customers were looking for an average of 300 MB per computer, whereas CDC's earliest 8-inch drives offered less than 60 MB. The 8-inch project was given low priority, and engineers assigned to its development kept getting pulled off to work on problems with 14-inch drives being designed for more important customers. Similar problems plagued the belated launches of Quantum's and Micropolis's 5.25-inch products.

3. In response to the needs of current customers, the marketing managers threw impetus behind alternative *sustaining* projects, such as incorporating better heads or developing new recording codes. These would give their cus-

tomers what they wanted, could be targeted at large markets, and generate the sales and profits required to maintain growth. Although they generally involved greater development expense, such sustaining investments appeared *far* less risky than investments in the disruptive technology, because the customers were there. The rationality of Seagate's decision to shelve the 3.5-inch drive in 1985–86, for example, is stark. Its view downmarket (in terms of Figure 2) was at a $50 million total market forecast for 3.5-inch drives in 1987. What gross margins it could achieve in that market were uncertain, but its manufacturing executives predicted that costs per megabyte in 3.5-inch drives would be much higher than in 5.25-inch products. Seagate's view upmarket was quite different. Volumes in 5.25-inch drives with capacities of 60–100 MB were forecast to be $500 million in size by 1987. And companies serving the 60–100 MB market were earning gross margins of 35–40 percent, whereas Seagate's margins in its high-volume 20 MB drives were between 25 and 30 percent. It simply did not make sense for Seagate to put resources behind the 3.5-inch drive, when competing proposals to move upmarket to develop its ST251 line of drives were also actively being evaluated.

After Seagate executives shelved the 3.5-inch project, it began introducing new 5.25-inch models at a dramatically accelerating rate. In the years 1985, 1986 and 1987, the numbers of new models it introduced each year as a percentage of the total number of its models on the market in the prior year were 57, 78, and 115 percent, respectively. And during the same period, Seagate incorporated complex and sophisticated new component technologies such as thin-film disks, voice coil actuators, RLL codes, and embedded, SCSI interfaces. In each of our other case studies as well, the established firms introduced new models in their established architectures employing an array of new component technologies at an accelerating rate, after the new architectures began to be sold. The clear motivation of the established firms in doing this was to win the competitive wars against each other, rather than to prepare for an attack by entrants from below.

4. New companies, usually including members of the frustrated engineering teams from established firms, were formed to exploit the disruptive product architecture. For example, the founders of the leading 3.5-inch drivemaker, Conner Peripherals, were disaffected employees from Seagate and Miniscribe, the two largest 5.25-inch manufacturers. The founders of 8-inch drive maker Micropolis came from Pertec, a 14-inch manufacturer; and the founders of Shugart and Quantum defected from Memorex.[11] The start-ups were as unsuccessful as their former employers in interesting established computer makers in the disruptive architecture. Consequently, they had to find *new* customers. The applications that emerged in this very uncertain, probing process were the minicomputer, the desktop personal computer, and the laptop (see Figure 2). These are obvious markets for hard drives in retrospect. But at the time, whether these would become significant markets for disk drives was highly uncertain. Micropolis was founded before the market for desk-side minicomputers and word processors, in which its products came to be used, emerged. Seagate was founded 2 years before IBM introduced its PC, when personal computers were simple toys for hobbyists. And Conner Peripherals got its start before Compaq knew the portable computer market had potential. The founders of these firms sold their products without a clear marketing strategy, essentially to whomever would buy them. Out of what was largely a trial-and-error approach to the market, the ultimately dominant applications for their products emerged.
5. Once the start-ups had found an operating base in new markets, they found that by adopting sustaining improvements in new component technologies,[12] they could increase the capacity of their drives at a faster rate than was required by their new market. As shown in Figure 2, they blazed trajectories of 50% annual improvement, fixing their sights on the large, established computer markets immedi-

[11] Ultimately, nearly all North American manufacturers of disk drives can trace their founders' genealogy to IBM's San Jose division, which developed and manufactured its magnetic recording products (Christensen, 1993).

[12] In general, these component technologies were developed within the largest of the established firms that dominated the markets above these entrants, in terms of the technology and market trajectories mapped in Figure 2.

ately above them on the performance scale. As noted above, the established firms' views downmarket, and the entrant firms' views upmarket, were asymmetrical. In contrast to the unattractive margins and market size the established firms saw when eyeing the new markets for simpler drives as they were emerging, the entrants tended to view the potential volumes and margins in the upscale, high-performance markets above them as highly attractive. Customers in these established markets eventually embraced the new architectures they had rejected earlier, because once their needs for capacity and speed were met, the new drives' smaller size and architectural simplicity made them cheaper, faster, and more reliable than the older architectures. For example, Seagate, which started in the desktop personal computer market, subsequently invaded and came to dominate the minicomputer, engineering workstation, and mainframe computer markets for disk drives. Seagate, in turn, was driven from the desktop personal computer market for disk drives by Conner and Quantum, the pioneering manufacturers of 3.5-inch drives.

6. When the smaller models began to invade established market segments, the drivemakers that had initially controlled those markets took their prototypes off the shelf (where they had been put in step #3), and defensively introduced them to defend their customer base in their own market.[13] By this time, of course, the new architecture had shed its disruptive character, and had become fully performance-competitive with the larger drives in the established markets. Although some established manufacturers were able to defend their market positions through belated introduction of the new architecture, many found that the entrant firms had developed insurmountable advantages in manufacturing cost and design experience, and they eventually withdrew from the market. For those established manufacturers that did succeed in introducing the new architectures, survival was the only reward. None of the firms we studied was ever able to win a significant share of the new market whose emergence had been enabled by the new architecture; the new drives simply cannibalized sales of older, larger-architecture products with existing customers. For example, as of 1991 almost none of Seagate's 3.5-inch drives had been sold to portable/laptop manufacturers: its 3.5-inch customers still were desktop computer manufacturers, and many of its 3.5-inch drives continued to be shipped with frames permitting them to be mounted in XT and AT-class computers that had been designed to accommodate 5.25-inch drives. Control Data, the 14-inch leader, never captured even a 1 percent share of the minicomputer market. It introduced its 8-inch drives nearly 3 years after the pioneering start-ups did, and nearly all of its drives were sold to its existing mainframe customers. Miniscribe, Quantum and Micropolis all had the same cannibalistic experience when they belatedly introduced disruptive-technology drives. They failed to capture a significant share of the new market, and at best succeeded in defending a portion of their prior business.

There are curious asymmetries in the *ex post* risks and rewards associated with sustaining and disruptive innovations. Many of the sustaining innovations (such as thin-film heads, thin film disks, and the 14-inch Winchester architecture) were *extremely* expensive and risky from a *technological* point of view. Yet because they addressed well-understood needs of known customers, perceived market risk was low; impetus coalesced; and resources were allocated with only prudent hesitation. Yet, although these innovations clearly helped the innovators retain their customers, there is no evidence from the industry's history that any firm was able to gain observable market share by virtue of such technology leadership.[14]

On the other hand, disruptive innovations were technologically straightforward: several established firms had already developed them by the time formal resource allocation decisions were

[13] Note that at this point, because the disruptive innovation invading below had become fully performance-competitive with the established technology, the innovation had essentially acquired the character of a sustaining innovation—it gave customers what they needed.

[14] Christensen (1992b) shows that there was no discernible first-mover advantage associated with trajectory-sustaining innovations, to firms in the disk drive industry. In contrast, there were *very* powerful first-mover advantages to leaders in trajectory-disruptive innovations that fostered the creation of new markets.

made. But these were viewed as extremely risky, because the markets were not 'there'. The most successful of the entrants that accepted the risks of creating new markets for disruptive innovations generated billions in revenues upon foundations of architectural technology that cost at most a few million dollars to put into place.

We argue that although differences in luck, resource endowments, managerial competence, and bureaucratic agility matter, the patterns of technology leadership displayed by established and entrant firms in the disk drive industry accurately reflect differences in the fully informed, rational *ex ante* perceptions of risks and rewards held by managers in the two types of firms. In each of the companies studied, a key task of senior managers was to decide which of the many product and technology development programs continually being proposed to them should receive a formal allocation of resources. The criteria used in these decisions were essentially the total return perceived in each project, adjusted by the perceived riskiness of the project, as these data were presented to them by mid-level managers. Projects targeted at the known needs of big customers in established markets consistently won the rational debates over resource allocation. Sophisticated systems for planning and compensation ensured that this would be the case.[15]

The contrast between the innovative behavior of some *individuals* in the firm, vs. the manner in which the firm's *processes* allocated resources across competing projects, is an important feature of this model.[16] In the cases studied, the pioneering engineers in established firms that developed disruptive-architecture drives were innovative not just in technology, but in their view of the market. They intuitively perceived opportunities for a very different disk drive. But organizational processes allocated resources based on rational assessments of data about returns and risks. Information provided by innovating engineers was at best hypothetical: without existing customers, they could only guess at the size of the market, the profitability of products, and required product performance. In contrast, current customers could articulate features, performance, and quantities they would purchase with *much* less ambiguity. Because of these differences in information clarity, firms were led toward particular sorts of innovations—many of which were extremely challenging and risky—and away from others. In the firms studied here, the issue does not seem so much to be innovativeness *per se*, as it is what *type* of innovation the firms' processes could facilitate.

In light of this research, the popular slogan, 'Stay close to your customers' (which is supported by the research of von Hippel, 1988, and others), appears not always to be robust advice. One instead might expect customers to lead their suppliers toward sustaining innovations, and to provide no leadership—or even to explicitly *mis*lead—in instances of disruptive technology change. Henderson (1993) saw similar potential danger for being held captive by customers in her study of photolithographic aligner equipment manufacturers.

We close our discussion of the model with a final note. Neglect of disruptive technologies proved damaging to established drivemakers because the trajectory of performance improvement that the technology *provided* was steeper than the improvement trajectory *demanded* in individual markets (see Figure 2.) The mismatch in these trajectories provided pathways for the firms that entered new markets eventually to become performance-competitive in established markets as well. If the trajectories were parallel, we would expect disruptive technologies to be deployed in new markets and to stay there; each successive market would constitute a relatively stable niche market out of which technologies and firms would not migrate.

[15] It is interesting that 20 years after Bower's (1970) study of resource allocation, we see in leading-edge systems for planning and compensation the same bias against risk taking. Morris and Ferguson's description of how IBM allowed Microsoft to gain control of PC operating system standards is centered on the role of mainframe producers in IBM's resource allocation process. In a 1990 interview with one of the authors, one of the most successful innovators in IBM history recounted how time and again he was forced to battle the controlling influence of middle-management's commitment to serve commercial mainframe customers.

[16] We are indebted to Professor Robert Burgelman for his comments on this issue. He has also noted, given the sequence of events we observed—where engineers inside the established firms began pursuing the disruptive product opportunity before the start-up entrants did—that timing matters a lot. It may be that when individuals in the established firms were pressing their ideas internally, they were too far ahead of the market. In the year or two that it took them to leave their employers, create new firms, and create new products, the nascent markets may have become more ready to accept the new drives.

THE LINKAGE BETWEEN MODELS OF RESOURCE DEPENDENCE AND RESOURCE ALLOCATION

We mentioned at the outset that a contribution of this paper is that it establishes a linkage between the school of thought known as *resource dependence* (Pfeffer and Salancik, 1978) and the models of the resource allocation process proposed by Bower (1970) and Burgelman (1983a, 1983b). Our findings support many of the conclusions of the resource dependence theorists, who contend that a firm's scope for strategic change is strongly bounded by the interests of external entities (customers, in this study) who provide the resources the firm needs to survive. We show that the mechanism through which customers wield this power is the process in which impetus coalesces behind investments in sustaining technologies, directing resources to innovations that address current customers' needs.

But although our findings lend support to the theory of resource dependence, they decidedly do not support a contention that managers are powerless to change the strategies of their companies in directions that are inconsistent with the needs of their customers as resource providers (Pfeffer and Salancik, 1978: 263–265).[17] The evidence from this study is that managers can, in fact, change strategy—but that they can successfully do so only if their actions are consistent with, rather than in counteraction to, the principle of resource dependence. In the disk drive industry's history, three established firms achieved a measure of commercial success in disruptive technologies. Two did so by spinning out organizations that were completely independent, in terms of customer relationships, from the mainstream groups. The third launched the disruptive technology with extreme managerial effort, from within the mainstream organization. This paper closes by summarizing these case histories and their implications for theory.

Distinct organizational units for small drives at Control Data

Control Data (CDC) was the dominant manufacturer of 14-inch disk pack and Winchester drives sold into the OEM market between 1975 and 1982: its market share fluctuated between 55 and 62 per cent. When the 8-inch architecture emerged in the late 1970s, CDC missed it by 3 years. It never captured more than 3–4 percent of the 8-inch market, and those 8-inch drives that it did sell, were sold almost exclusively to its established customer base of mainframe computer manufacturers. The reason given by those interviewed in this study was that engineers and marketers kept getting pulled off the 8-inch program to resolve problems in the launch of next-generation 14-inch products for CDC's mainstream customers.

CDC also launched its first 5.25-inch model 2 years after Seagate's pioneering product appeared in 1980. This time, however, CDC located its 5.25-inch effort in Oklahoma City—according to one manager, 'not to escape CDC's Minneapolis engineering culture, but to isolate the (5.25-inch product) group from the company's mainstream customers. We needed an organization that could get excited about a $50,000 order. In Minneapolis (which derived nearly $1 billion from the sale of 14-inch drives in the mainframe market) you needed a million-dollar order just to turn anyone's head.' Although it was late and never reascended to its position of dominance, CDC's foray into 5.25-inch drives was profitable, and at times it commanded a 20 percent share of higher-capacity 5.25-inch drives.

Having learned from its experience in Oklahoma City, when CDC decided to attack the 3.5-inch market it set up yet another organization in Simi Valley, California. This group shipped its first products in mid-1988, about 18 months behind Conner Peripherals, and enjoyed modest commercial success. The creation of these stand-alone organizations was CDC's way of handling the 'strategic forcing' and 'strategic context determination' challenges described by Burgelman (1983b, 1984).

[17] In Chapter 10 of Pfeffer and Salancik's (1978) book, for example, they assert that the manager's most valuable role is symbolic, and they cite a hypothetical example. When external forces induce hard times in a company, managers can usefully be fired—not because bringing in a new manager will make any difference to the performance of the organization, but because of the symbolic content of that action. It creates the *feeling* in the organization that something is being done to address this problem, even though it will have no effect. The evidence from these case studies does not support this assertion about the ability of managers to change the course of their organizations. *As long as managers act in a manner consistent with the forces of resource dependence*, it appears that they can, indeed, wield significant power.

Quantum Corporation and the 3.5-inch Hardcard

Quantum Corporation, a leading maker of 8-inch drives sold in the minicomputer market, introduced its first 5.25-inch product 3 years after those drives had first appeared in the market. As the 5.25-inch pioneers began to invade the minicomputer market from below, for all of the reasons described above, Quantum launched a 5.25-inch product and was temporarily successful in defending some of its existing customers by selling its 5.25-inch drive to them. But it never sold a single drive into the desktop PC market, and its overall sales began to sag. In 1984 a group of Quantum engineers saw a market for a thin 3.5-inch drive plugged into an expansion slot in IBM XT- and AT-class desktop computers—drives that would be sold to end-users, rather than OEM computer manufacturers. Quantum financed and retained 80 percent ownership of this spin-off venture, called Plus Development Corporation, and set the company up in different facilities. Plus was extremely successful. As sales of Quantum's line of 8-inch drives began to evaporate in the mid-1980s, they were offset by Plus's growing 'Hardcard' revenues. By 1987, sales of 8 and 5.25-inch products had largely evaporated. Quantum purchased the 20 percent of Plus it did not own; essentially closed down the old corporation, and installed Plus's executives in Quantum's most senior positions. They then reconfigured Plus's 3.5-inch products to appeal to desktop computer makers such as Apple, just as the capacity vector for 3.5-inch drives was invading the desktop, as shown in Figure 2. By 1994 the new Quantum had become the largest unit-volume producer of disk drives in the world. Quantum's spin-out of the Hardcard effort and its subsequent strategic reorientation appears to be an example of the processes of strategy change described in Burgelman (1991).

Micropolis: Transition through managerial force

Managers at Micropolis Corporation, also an 8-inch drivemaker, employed a very different approach in which senior management initiated a disruptive program within the mainstream organization that made 8-inch drives. As early as 1982, Micropolis' founder and CEO, Stuart Mabon, intuitively saw the trends mapped in Figure 2 and decided the firm needed to become primarily a maker of 5.25-inch drives. While initially hoping to keep adequate resources focused on the 8-inch line that Micropolis could straddle both markets,[18] he assigned the company's premier engineers to the 5.25-inch program. Mabon recalls that it took '100% of his time and energy for 18 months' to keep adequate resources focused on the 5.25-inch program, because the organization's own mechanisms allocated resources to where the customers were: 8-inch drives. By 1984 Micropolis had failed to keep pace with competition in the minicomputer market for disk drives, and withdrew its remaining 8-inch models. With Herculean effort, however, it did succeed in its 5.25-inch programs. Figure 3 shows why this was necessary: in the transition, Micropolis assumed a position on a very different technological trajectory (Dosi, 1982). In the process it had to walk away from every one of its major customers, and replace the lost revenues with sales of the new product line to an entirely different group of desktop computer makers. Mabon remembers the experience as the most exhausting of his life. Micropolis aborted a 1989 attempt to launch its first 3.5-inch drive, and as of 1992 the company still had not introduced a 3.5-inch product.

Table 4 arrays the experiences of the six companies we studied in depth, as they addressed disruptive technologies from within their mainstream organization, and through independent organizations. Companies are classed as having been successful in this table if their market share in the new market enabled by the disruptive disk drive technology was at least 25% of its percentage share in the prior, established market in which it was dominant. Hence, Control Data, whose share of the 14-inch mainframe computer disk drive market often exceeded 60 percent, was classed as a

[18] The failure of Micropolis to maintain simultaneous competitive commitments to its established technology while adequately nurturing the 5.25-inch technology is consistent with the technological histories recounted in Utterback (1994). Utterback found historically that firms that attempted to develop radically new technology almost always tried simultaneously to maintain their commitments to the old; and that they almost always failed.

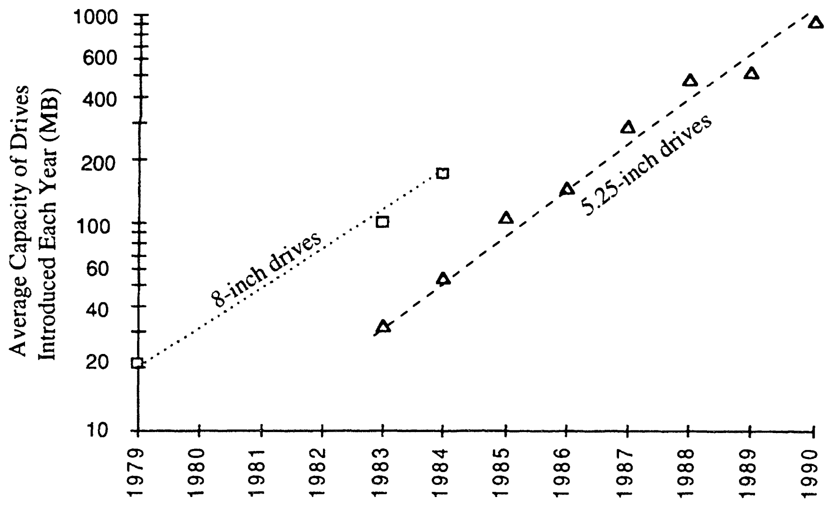

Figure 3. The disruptive impact of 5.25-inch drives on the market position of Micropolis Corp.

failure in its attempt to sell 8-inch drives, because its share of minicomputer disk drives never exceeded 3 percent. Its share of 5.25-inch drives sold to the desktop workstation market, however, reached 20 percent, and it was therefore classed as a success in that effort. An organization was defined as being independent from the mainstream if it was geographically separated; was held accountable for full profit and loss; and included within it all of the functional units of a typical company: sales and marketing, manufacturing, finance, human resources, engineering, and so on.

In addition to the six firms studied in depth, Table 4 lists other firms, shown in *italic type*, whose histories were researched through public sources and a more limited number of personal interviews. The 'L' and 'T' shown next to each company in the table, as in Table 3, denotes whether that firm's experience lends literal or theoretical support (Yin, 1989) to the proposition that managers can effect a strategy change despite resource dependence, by creating independent organizations that depend exclusively upon resources in the targeted market. Micropolis' transition from 8 to 5.25-inch drives is classed as a theoretical replication, because of the enormous managerial effort that was required to counteract the force of resource dependence in that transition.[19] Note that in every instance except Micropolis' 5.25-inch entry, firms that *fought* the forces of resource dependence by attempting to commercialize disruptive technology from within their mainstream organizations failed, as measured by *Disk/Trend* data. And the firms that *accounted for* the forces of resource dependence by spinning out independent organizations succeeded.

Note in Table 4 that there do not seem to be strong firm or managerial effects, compared to the organizational effect. Control Data, Quantum, and Micropolis encountered multiple disruptive technologies; and *the same general managers sat atop these organizations across each of these transitions*. What seems to have distinguished these firms' successful from failed attempts to commercialize these disruptive technologies was not the talent of the managers *per se*, but whether the managers created organizationally distinct units to accomplish the task—where the forces of resource dependence could work in their favor, rather than against them. The successful cases cited here are the only ones in the industry's history in which a leading incumbent stayed atop its market when faced with disruptive technological change—and as a result, the number of data points in the top half of the matrix is limited. But these

[19] The success or failure of these other firms at each point of disruptive technology change was unambiguously determinable from *Disk/Trend Report* data. Similarly, whether these firms managed the launch of disruptive technology products from within their mainstream organization, or through an organizationally separate unit, was a matter of public record and general industry knowledge. Hence, there were no subjective judgments involved in constructing Table 4.

Table 4. The success and failure of companies addressing disruptive technologies through mainstream vs. independent organizations

Succeeded	Control Data 5.25-inch (L) Control Data 3.5-inch (L) Quantum 3.5-inch (L) *Maxtor 3.5-inch (L)*	Micropolis 5.25-inch (T)
Failed		Control Data 8-inch (L) Quantum 5.25-inch (L) Miniscribe 3.5-inch (L) Seagate 3.5-inch (L) Micropolis 3.5-inch (L) *Memorex 8-inch (L)* *Memorex 5.25-inch (L)* *Priam 5.25-inch (L)* *Century Data 8-inch (L)* *Ampex 8-inch (L)* *Ampex 5.25-inch (L)*
	Commercialized from within an independent organization.	Commercialized from within the mainstream organization.

findings do suggest that, while the forces of resource dependence act as strong constraints on managerial discretion, managers can in fact manipulate those constraints effectively in order to achieve strategic change.

CONCLUSIONS

This study highlights an important issue for managers and scholars who strive to understand the reasons why strong, capably managed firms stumble when faced with particular types of technological change. While many scholars see the issue primarily as an issue of *technological competence*, we assert that at a deeper level it may an issue of *investment*. We have observed that when competence was lacking, but impetus from customers to develop that competence was sufficiently strong, established firms successfully led their industries in developing the competencies required for sustaining technological change. Importantly, because sustaining technologies address the interests of established firms' existing customers, we saw that technological change could be achieved without strategy change.

Conversely, when technological competence existed, but impetus from customers was lacking, we saw consistently that firms were unable to commercialize what they already could do. This is because disruptive technologies initially tend to be saleable only in different markets whose economic and financial characteristics render them unattractive to established firms. Addressing these technologies therefore requires a change in strategy in order to attack a very different market. In the end, it appears that although the stumbles of these established firms are *associated* with technological change, the key issue appears to be firms' disabilities in changing strategy, not technology.

Our model is not presented as the path every firm follows when faced with disruptive technology. We believe, however, that it may contribute several insights for scholars interested in the factors that affect strategic change in firms. First, it notes that the allocation of resources to some product development and commercialization programs, and the denial of resources to others, is a key event or decision in the implementation of strategy. The model highlights the process by which impetus and consequent resources may be denied to technological opportunities that do not contribute to the needs of prominent customers. These findings suggest a causal relationship might exist between resource allocation processes, as modeled by Bower (1970) and Burgelman (1983a, 1983b), and the phenomenon of resource dependence (Pfeffer and Salancik, 1978). Our findings suggest that despite the powerful forces of resource dependence, however, managers can, in fact, wield considerable power, and wield it effectively, in changing the strategic course of their firms in directions other than those in which its resource providers are pulling it. By understanding the processes that link customer needs, impetus, and resource allocation, managers can align efforts to commercialize disruptive technology (which entails a change in strategy) with the forces of resource dependence. This involves managing disruptive technology in a manner that is out of the organizational and strategic context of mainstream organizations—where of necessity, incentives and resource allocation processes are designed to nourish sustaining innovations that address current customers' needs. In this way, the model and these case studies illustrate the mechanisms through which autonomous and induced strategic behavior (Burgelman, 1983a) can affect, or fail to affect, a company's course.

Much additional research must be done. Efforts to explore the external validity and usefulness of the model through studies of sustaining and disruptive technological change in other industries has begun (Rosenbloom and Christensen, 1995), but much more is required. In addition, we hope that future researchers can develop clearer models for managerial action and strategic change in the face of disruptive technology change that are consistent with the principles of resource dependence and the processes of resource allocation.

ACKNOWLEDGEMENTS

We gratefully acknowledge the financial support of the Harvard Business School Division of Research in conducting the research for this paper, and thank the editors of *Disk/Trend Report* for sharing their industry data with us. We are indebted to Professors Robert Burgelman of Stanford University, Rebecca Henderson of the Massachusetts Institute of Technology, David Garvin and several of our other colleagues at the Harvard Business School, as well as the anonymous referees, for invaluable suggestions for improving earlier versions of this paper. Any remaining deficiencies are our sole responsibility.

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APPENDIX 1: A BRIEF PRIMER ON HOW DISK DRIVES WORK

Rigid disk drives are comprised of one or more rotating disks—polished aluminum platters coated with magnetic material—mounted on a central spindle. Data are recorded and read on concentric tracks on the surfaces of these disks. Read/write heads—one each for the top and bottom surfaces of each disk on the spindle—are aerodynamically designed to fly a few millionths of an inch over the surface of the disk. They generally rest on the disk's surface when the drive is at rest; 'take off' as the drive begins to spin; and 'land' again when the disks stop. The heads are positioned over the proper track on the disk by an actuator motor, which moves the heads across the tracks in a fashion similar to the arm on a phonograph. The head is essentially a tiny electromagnet which, when current flows in one direction, orients the polarity of the magnetic domain on the disk's surface immediately beneath it. When the direction of current through the electromagnet reverses, its polarity changes. This induces an opposite switch of the polarity of the adjacent domain on the disk's surface as the disk spins beneath the head. In this manner, data are written in binary code on the disk. To read data, changes in magnetic field on the disk as it spins beneath the head are used to induce changes in the direction of current—essentially the reverse process of writing. Disk drives also include electronic circuitry enabling computers to control and communicate with the drive.

As in other magnetic recording products, *areal recording density* (measured in megabits per square inch of disk surface area, or mbpsi) was the pervasive measure of product performance in the disk drive industry. Historically, areal density in the industry has increased at a steady 35 percent annual rate. A drive's total capacity is the product of the available square inches on the top and bottom surfaces of the disks mounted on the spindle of the drive, multiplied by its areal recording density. Historically, the capacity of drives in a given product architecture has increased at about 50 percent annually. The difference between the 35 percent increase in areal density and the 50 percent increase in total capacity has come from mechanical engineering innovations, which enable manufacturers to squeeze additional disks and heads into a given size of drive.

APPENDIX 2: CALCULATION OF THE TRAJECTORIES MAPPED IN FIGURE 2

The trajectories mapped in Figure 2 were calculated as follows. Data on the capacity provided with computers in the mainframe, minicomputer, desktop personal computer, and portable computer classes were obtained from *Data Sources*, an annual publication that lists the technical specifications of all computer models available from each computer manufacturer. Where particular models were available with different features and configurations, the manufacturer provided *Data Sources* with a 'typical' system configuration, with defined RAM capacity, performance specifications of peripheral equipment (including disk drives), list price, and year of introduction. In instances where a given computer model was offered for sale over a sequence of years, the hard disk capacity provided in the typical configuration generally increased. *Data Sources* divides computers into mainframe, mini/midrange, desktop personal, portable and laptop, and notebook computers. For each class of computers, all models available for sale in each year were ranked by price, and the hard disk capacity provided with the median-priced model was identified, for each year. The best-fit line through the resultant time series for each class of computer is plotted as the solid lines in Figure 2. These single solid lines are drawn in Figure 2 for expository simplification, to indicate the trend in typical machines. In reality, of course, there is a wide band around these lines. The leading and trailing edges of performance—the highest and lowest capacities offered with the most and least expensive computers— were substantially higher and lower, respectively, than the typical values mapped in Figure 2.

The dotted lines in Figure 2 represent the best-fit line through the unweighted average capacity of all disk drives introduced for sale in each given architecture, for each year. These data were taken from *Disk/Trend Report*. Again, for expository simplification, only this average line is shown. There was a wide band of capacities introduced for sale in each year, so that the highest-capacity drive introduced in each year was substantially above the average shown. Stated in another way, a distinction must be made between the full range of products available for purchase, and those in typical systems of use. The upper and lower bands around the median and average trajectories in Figure 2 are generally parallel to the lines shown.

Because higher-capacity drives were available than the capacities offered with the median-priced systems, we state in the text that the solid-line trajectories in Figure 2 represent the capacities 'demanded' in each market. In other words, the capacity per machine was not constrained by technological availability. Rather, it represents a *choice* for hard disk capacity, made by computer users, given the prevailing cost.