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THE INNOVATOR'S DILEMMA

WHEN NEW TECHNOLOGIES CAUSE GREAT FIRMS TO FAIL //

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In Gratitude

Although this book lists only one author, in reality the ideas it molds together were contributed and refined by many extraordinarily insightful and selfless colleagues. The work began when Professors Kim Clark, Joseph Bower, Jay Light, and John McArthur took the risk of admitting and financing a middle-aged man's way into and through the Harvard Business School's doctoral program in 1989. In addition to these mentors, Professors Richard Rosenbloom, Howard Stevenson, Dorothy Leonard, Richard Walton, Bob Hayes, Steve Wheelwright, and Kent Bowen helped throughout my doctoral research to keep my thinking sharp and my standards for evidence high, and to embed what I was learning within the streams of strong scholarship that had preceded what I was attempting to research. None of these professors needed to spend so much of their busy lives guiding me as they did, and I will be forever grateful for what they taught me about the substance and process of scholarship.

I am similarly indebted to the many executives and employees of companies in the disk drive industry who opened their memories and records to me as I tried to understand what had driven them in the particular courses they had taken. In particular, James Porter, editor of *Disk/Trend Report*, opened his extraordinary archives of data, enabling me to measure what has happened in the disk drive industry with a level of completeness and accuracy that could be done in few other settings. The model of the industry's evolution and revolution that these men and women helped me construct has formed the theoretical backbone for this book. I hope they find it to be a useful tool for making sense of their past, and a helpful guide for some of their decisions in the future.

During my tenure on the Harvard Business School faculty, other colleagues have helped refine this book's ideas even more. Professors Rebecca Henderson and James Utterback of MIT, Robert Burgelman of Stanford, and David Garvin, Gary Pisano, and Marco Iansiti of the Harvard Business School have been particularly helpful. Research associates Rebecca Voorheis, Greg Rogers, Bret Baird, Jeremy Dann, Tara Donovan, and Michael Overdorf; editors Marjorie Williams, Steve Prokesch, and Barbara Feinberg; and assistants Cheryl Druckenmiller, Meredith Anderson, and Marguerite Dole, have likewise contributed untold amounts of data, advice, insight, and work.

I am grateful to my students, with whom I have discussed and refined the ideas put forward in this book. On most days I leave class wondering why I get paid and why my students pay tuition, given that it is I who have learned the most from our interactions. Every year they leave our school with their degrees and scatter around the world, without understanding how much they have taught their teachers. I love them and hope that those who come across this book will be able to recognize in it the fruits of their puzzled looks, questions, comments, and criticisms.

My deepest gratitude is to my family—my wife Christine and our children Matthew, Ann, Michael, Spencer, and Catherine. With unhesitating faith and support they encouraged me to pursue my lifelong dream to be a teacher, amidst all of the demands of family life. Doing this research on disruptive technologies has indeed been disruptive to them in terms of time and absence from home, and I am forever grateful for their love and support. Christine, in particular, is the smartest and most patient person I have known. Most of the ideas in this book went home on some night over the past five years

in half-baked condition and returned to Harvard the next morning having been clarified, shaped, and edited through my conversations with her. She is a great colleague, supporter, and friend. I dedicate this book to her and our children.

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Introduction

This book is about the failure of companies to stay atop their industries when they confront certain types of market and technological change. It's not about the failure of simply any company, but of *good* companies—the kinds that many managers have admired and tried to emulate, the companies known for their abilities to innovate and execute. Companies stumble for many reasons, of course, among them bureaucracy, arrogance, tired executive blood, poor planning, short-term investment horizons, inadequate skills and resources, and just plain bad luck. But this book is not about companies with such weaknesses: It is about well-managed companies that have their competitive antennae up, listen astutely to their customers, invest aggressively in new technologies, and yet still lose market dominance.

Such seemingly unaccountable failures happen in industries that move fast and in those that move slow; in those built on electronics technology and those built on chemical and mechanical technology; in manufacturing and in service industries. Sears Roebuck, for example, was regarded for decades as one of the most astutely managed retailers in the world. At its zenith Sears accounted for more than 2 percent of all retail sales in the United States. It pioneered several innovations critical to the success of today's most admired retailers: for example, supply chain management, store brands, catalogue retailing, and credit card sales. The esteem in which Sears' management was held shows in this 1964 excerpt from *Fortune:* "How did Sears do it? In a way, the most arresting aspect of its story is that there was no gimmick. Sears opened no big bag of tricks, shot off no skyrockets. Instead, it looked as though everybody in its organization simply did the right thing, easily and naturally. And their cumulative effect was to create an extraordinary powerhouse of a company." [1]

Yet no one speaks about Sears that way today. Somehow, it completely missed the advent of discount retailing and home centers. In the midst of today's catalogue retailing boom, Sears has been driven from that business. Indeed, the very viability of its retailing operations has been questioned. One commentator has noted that "Sears' Merchandise Group lost $1.3 billion (in 1992) even before a $1.7 billion restructuring charge. Sears let arrogance blind it to basic changes taking place in the American marketplace." [2] Another writer has complained,

> Sears has been a disappointment for investors who have watched its stock sink dismally in the face of unkept promises of a turnaround. Sears' old merchandising approach—a vast, middle-of-the-road array of mid-priced goods and services—is no longer competitive. No question, the constant disappointments, the repeated predictions of a turnaround that never seems to come, have reduced the credibility of Sears' management in both the financial and merchandising communities. [3]

It is striking to note that Sears received its accolades at exactly the time—in the mid-1960s—when it was ignoring the rise of discount retailing and home centers, the lower-cost formats for marketing name-brand hard goods that ultimately stripped Sears of its core franchise. Sears was praised as one of the best-managed companies in the world at the very time it let Visa and MasterCard usurp the enormous lead it had established in the use of credit cards in retailing.

In some industries this pattern of leadership failure has been repeated more than once. Consider the computer industry. IBM dominated the mainframe market but missed by years the emergence of minicomputers, which were technologically much simpler than mainframes. In fact, no other major manufacturer of mainframe computers became a significant player in the minicomputer business. Digital Equipment Corporation created the minicomputer market and was joined by a set of other aggressively managed companies: Data General, Prime, Wang, Hewlett-Packard, and Nixdorf. But each of these companies in turn missed the desktop personal computer market. It was left to Apple Computer, together with Commodore, Tandy, and IBM's stand-alone PC division, to create the personal-computing market. Apple, in particular, was uniquely innovative in establishing the standard for user-friendly computing. But Apple and IBM lagged five years behind the leaders in bringing portable computers to market. Similarly, the firms that built the engineering workstation market—Apollo, Sun, and Silicon Graphics—were all newcomers to the industry.

As in retailing, many of these leading computer manufacturers were at one time regarded as among the best-managed companies in the world and were held up by journalists and scholars of management as examples for all to follow. Consider this assessment of Digital Equipment, made in 1986: "Taking on Digital Equipment Corp. these days is like standing in front of a moving train. The $7.6 billion computer maker has been gathering speed while most rivals are stalled in a slump in the computer industry." [4] The author proceeded to warn IBM to watch out, because it was standing on the tracks. Indeed, Digital was one of the most prominently featured companies in the McKinsey study that led to the book *In Search of Excellence*.[5]

Yet a few years later, writers characterized DEC quite differently:

> Digital Equipment Corporation is a company in need of triage. Sales are drying up in its key minicomputer line. A two-year-old restructuring plan has failed miserably. Forecasting and production planning systems have failed miserably. Cost-cutting hasn't come close to restoring profitability.... But the real misfortune may be DEC's lost opportunities. It has squandered two years trying halfway measures to respond to the low-margin personal computers and workstations that have transformed the computer industry. [6]

In Digital's case, as in Sears, the very decisions that led to its decline were made at the time it was so widely regarded as being an astutely managed firm. It was praised as a paragon of managerial excellence at the very time it was ignoring the arrival of the desktop computers that besieged it a few years later.

Sears and Digital are in noteworthy company. Xerox long dominated the market for plain paper photocopiers used in large, high-volume copying centers. Yet it missed huge growth and profit opportunities in the market for small tabletop photocopiers, where it became only a minor player. Although steel minimills have now captured 40 percent of the North American steel market, including nearly all of the region's markets for bars, rods, and structural steel, not a *single* integrated steel company— American, Asian, or European—had by 1995 built a plant using minimill technology. Of the thirty manufacturers of cable-actuated power shovels, only four survived the industry's twenty-five-year transition to hydraulic excavation technology.

As we shall see, the list of leading companies that failed when confronted with disruptive changes in technology and market structure is a long one. At first glance, there seems to be no pattern in the changes that overtook them. In some cases the new technologies swept through quickly; in others, the transition took decades. In some, the new technologies were complex and expensive to develop. In others, the deadly technologies were simple extensions of what the leading companies already did better than anyone else. One theme common to all of these failures, however, is that the decisions that led to failure were made when the leaders in question were widely regarded as among the best companies in the world.

There are two ways to resolve this paradox. One might be to conclude that firms such as Digital, IBM, Apple, Sears, Xerox, and Bucyrus Erie must *never* have been well managed. Maybe they were successful because of good luck and fortuitous timing, rather than good management. Maybe they finally fell on hard times because their good fortune ran out. Maybe. An alternative explanation, however, is that these failed firms were as well-run as one could expect a firm managed by mortals to be—but that there is something about the way decisions get made in successful organizations that sows the seeds of eventual failure.

The research reported in this book supports this latter view: It shows that in the cases of well-managed firms such as those cited above, *good* management was the most powerful reason they failed to stay atop their industries. Precisely *because* these firms listened to their customers, invested aggressively in new technologies that would provide their customers more and better products of the sort they wanted, and because they carefully studied market trends and systematically allocated investment capital to innovations that promised the best returns, they lost their positions of leadership.

What this implies at a deeper level is that many of what are now widely accepted principles of good management are, in fact, only situationally appropriate. There are times at which it is right *not* to listen to customers, right to invest in developing lower-performance products that promise *lower* margins, and right to aggressively pursue small, rather than substantial, markets. This book derives a set of rules, from carefully designed research and analysis of innovative successes and failures in the disk drive and other industries, that managers can use to judge when the widely accepted principles of good management should be followed and when alternative principles are appropriate.

These rules, which I call *principles of disruptive innovation*, show that when good companies fail, it often has been because their managers either ignored these principles or chose to fight them. Managers can be extraordinarily effective in managing even the most difficult innovations if they work to understand and harness the principles of disruptive innovation. As in many of life's most challenging endeavors, there is great value in coming to grips with "the way the world works," and in managing innovative efforts in ways that accommodate such forces.

The Innovator's Dilemma is intended to help a wide range of managers, consultants, and academics in manufacturing and service businesses—high tech or low—in slowly evolving or rapidly changing environments. Given that aim, *technology*, as used in this book, means the processes by which an organization transforms labor, capital, materials, and information into products and services of greater value. All firms have technologies. A retailer like Sears employs a particular technology to procure, present, sell, and deliver products to its customers, while a discount warehouse retailer like PriceCostco employs a different technology. This concept of technology therefore extends beyond engineering and manufacturing to encompass a range of marketing, investment, and managerial processes. *Innovation* refers to a change in one of these technologies.

THE DILEMMA

To establish the theoretical depth of the ideas in this book, the breadth of their usefulness, and their applicability to the future as well as the past, I have divided this book into two parts. Part One, chapters 1 through 4, builds a framework that explains why sound decisions by great managers can lead firms to failure. The picture these chapters paint is truly that of an innovator’s dilemma: the logical, competent decisions of management that are critical to the success of their companies are also the reasons why they lose their positions of leadership. Part Two, chapters 5 through 10, works to resolve the dilemma. Building on our understanding of why and under what circumstances new technologies have caused great firms to fail, it prescribes managerial solutions to the dilemma—how executives can simultaneously do what is right for the near-term health of their established businesses, while focusing adequate resources on the disruptive technologies that ultimately could lead to their downfall.

Building a Failure Framework

I begin this book by digging deep before extending the discussion to draw general conclusions. The first two chapters recount in some detail the history of the disk drive industry, where the saga of "good-companies-hitting-hard-times" has been played out over and over again. This industry is an ideal field for studying failure because rich data about it exist and because, in the words of Harvard Business School Dean Kim B. Clark, it is "fast history." In just a few years, market segments, companies, and technologies have emerged, matured, and declined. Only twice in the six times that new architectural technologies have emerged in this field has the industry's dominant firm maintained its lead in the subsequent generation. This repetitive pattern of failure in the disk drive industry allowed me first to develop a preliminary framework that explained why the best and largest firms in the early generations of this industry failed and then to test this framework across subsequent cycles in the industry's history to see whether it was robust enough to continue to explain failures among the industry's more recent leaders.

Chapters 3 and 4 then deepen our understanding of why the leading firms stumbled repeatedly in the disk drive industry and, simultaneously, test the breadth of the framework's usefulness by examining the failure of firms in industries with very different characteristics. Hence, chapter 3, exploring the mechanical excavator industry, finds that the same factors that precipitated the failure of the leading disk drive makers also proved to be the undoing of the leading makers of mechanical excavators, in an industry that moves with a very different pace and technological intensity. Chapter 4 completes the framework and uses it to show why integrated steel companies worldwide have proven so incapable of blunting the attacks of the minimill steel makers.

WHY GOOD MANAGEMENT CAN LEAD TO FAILURE

The failure framework is built upon three findings from this study. The first is that there is a strategically important distinction between what I call *sustaining* technologies and those that are *disruptive.* These concepts are very different from the incremental-versus-radical distinction that has characterized many studies of this problem. Second, the pace of technological progress can, and often does, outstrip what markets need. This means that the relevance and competitiveness of different technological approaches can change with respect to different markets over time. And third, customers and financial structures of successful companies color heavily the sorts of investments that appear to be attractive to them, relative to certain types of entering firms.

Sustaining versus Disruptive Technologies

Most new technologies foster improved product performance. I call these *sustaining technologies*. Some sustaining technologies can be discontinuous or radical in character, while others are of an incremental nature. What all sustaining technologies have in common is that they improve the performance of established products, along the dimensions of performance that mainstream customers in major markets have historically valued. Most technological advances in a given industry are sustaining in character. An important finding revealed in this book is that rarely have even the most radically difficult sustaining technologies precipitated the failure of leading firms.

Occasionally, however, *disruptive technologies* emerge: innovations that result in *worse* product performance, at least in the near-term. Ironically, in each of the instances studied in this book, it was disruptive technology that precipitated the leading firms' failure.

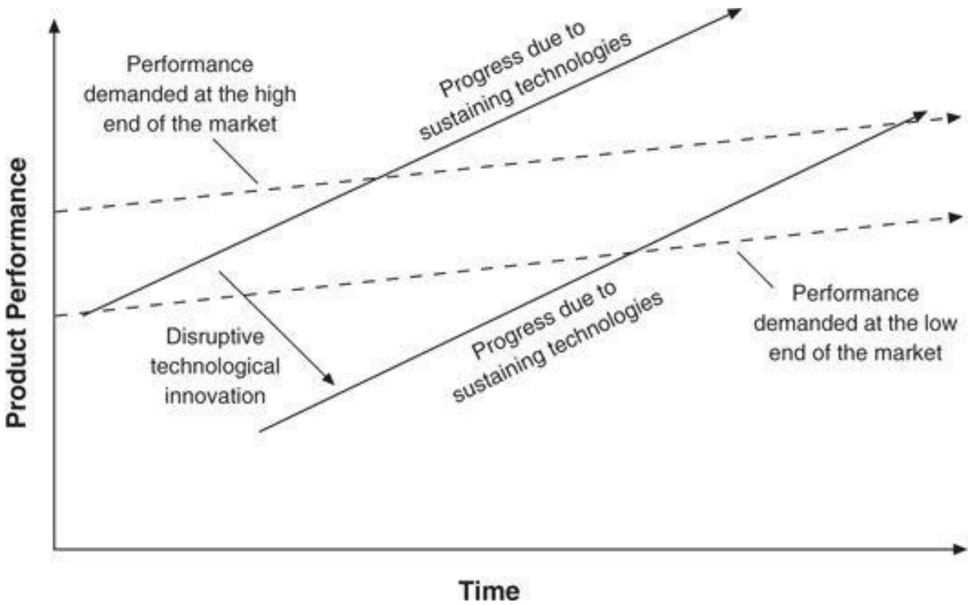
Disruptive technologies bring to a market a very different value proposition than had been available previously. Generally, disruptive technologies underperform established products in mainstream markets. But they have other features that a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and, frequently, more convenient to use. There are many examples in addition to the personal desktop computer and discount retailing examples cited above. Small off-road motorcycles introduced in North America and Europe by Honda, Kawasaki, and Yamaha were disruptive technologies relative to the powerful, over-the-road cycles made by Harley-Davidson and BMW. Transistors were disruptive technologies relative to vacuum tubes. Health maintenance organizations were disruptive technologies to conventional health insurers. In the near future, "internet appliances" may become disruptive technologies to suppliers of personal computer hardware and software.

Trajectories of Market Need versus Technology Improvement

The second element of the failure framework, the observation that technologies can progress faster than market demand, illustrated in Figure I.1, means that in their efforts to provide better products than their competitors and earn higher prices and margins, suppliers often “overshoot” their market: They give customers more than they need or ultimately are willing to pay for. And more importantly, it means that disruptive technologies that may underperform today, relative to what users in the market demand, may be fully performance-competitive in that same market tomorrow.

Many who once needed mainframe computers for their data processing requirements, for example, no longer need or buy mainframes. Mainframe performance has surpassed the requirements of many original customers, who today find that much of what they need to do can be done on desktop machines linked to file servers. In other words, the needs of many computer users have increased more slowly than the rate of improvement provided by computer designers. Similarly, many shoppers who in 1965 felt they had to shop at department stores to be assured of quality and selection now satisfy those needs quite well at Target and Wal-Mart.

Figure I.1 The Impact of Sustaining and Disruptive Technological Change



Disruptive Technologies versus Rational Investments

The last element of the failure framework, the conclusion by established companies that investing aggressively in disruptive technologies is not a rational financial decision for them to make, has three bases. First, disruptive products are simpler and cheaper; they generally promise lower margins, not greater profits. Second, disruptive technologies typically are first commercialized in emerging or insignificant markets. And third, leading firms' most profitable customers generally don't want, and indeed initially can't use, products based on disruptive technologies. By and large, a disruptive technology is initially embraced by the least profitable customers in a market. Hence, most companies with a practiced discipline of listening to their best customers and identifying new products that promise greater profitability and growth are rarely able to build a case for investing in disruptive technologies until it is too late.

TESTING THE FAILURE FRAMEWORK

This book defines the problem of disruptive technologies and describes how they can be managed, taking care to establish what researchers call the *internal* and *external* validity of its propositions. Chapters 1 and 2 develop the failure framework in the context of the disk drive industry, and the initial pages of chapters 4 through 8 return to that industry to build a progressively deeper understanding of why disruptive technologies are such vexatious phenomena for good managers to confront successfully. The reason for painting such a complete picture of a single industry is to establish the internal validity of the failure framework. If a framework or model cannot reliably explain what happened within a single industry, it cannot be applied to other situations with confidence.

Chapter 3 and the latter sections of chapters 4 through 9 are structured to explore the external validity of the failure framework—the conditions in which we might expect the framework to yield useful insights. Chapter 3 uses the framework to examine why the leading makers of cable excavators were driven from the earthmoving market by makers of hydraulic machines, and chapter 4 discusses why the world's integrated steel makers have floundered in the face of minimill technology. Chapter 5 uses the model to examine the success of discount retailers, relative to conventional chain and department stores, and to probe the impact of disruptive technologies in the motor control and printer industries. Chapter 6 examines the emerging personal digital assistant industry and reviews how the electric motor control industry was upended by disruptive technology. Chapter 7 recounts how entrants using disruptive technologies in motorcycles and logic circuitry dethroned industry leaders; chapter 8 shows how and why computer makers fell victim to disruption; and chapter 9 spotlights the same phenomena in the accounting software and insulin businesses. Chapter 10 applies the framework to a case study of the electric vehicle, summarizing the lessons learned from the other industry studies, showing how they can be used to assess the opportunity and threat of electric vehicles, and describing how they might be applied to make an electric vehicle commercially successful. Chapter 11 summarizes the book's findings.

Taken in sum, these chapters present a theoretically strong, broadly valid, and managerially practical framework for understanding disruptive technologies and how they have precipitated the fall from industry leadership of some of history's best-managed companies.

HARNESSING THE PRINCIPLES OF DISRUPTIVE INNOVATION

Colleagues who have read my academic papers reporting the findings recounted in chapters 1 through 4 were struck by their near-fatalism. If good management practice drives the failure of successful firms faced with disruptive technological change, then the usual answers to companies' problems—planning better, working harder, becoming more customer-driven, and taking a longer-term perspective—all *exacerbate* the problem. Sound execution, speed-to-market, total quality management, and process reengineering are similarly ineffective. Needless to say, this is disquieting news to people who teach future managers!

Chapters 5 through 10, however, suggest that although the solution to disruptive technologies cannot be found in the standard tool kit of good management, there are, in fact, sensible ways to deal effectively with this challenge. Every company in every industry works under certain forces—laws of organizational nature—that act powerfully to define what that company can and cannot do. Managers faced with disruptive technologies fail their companies when these forces overpower them.

By analogy, the ancients who attempted to fly by strapping feathered wings to their arms and flapping with all their might as they leapt from high places invariably failed. Despite their dreams and hard work, they were fighting against some very powerful forces of nature. No one could be strong enough to win this fight. Flight became possible only after people came to understand the relevant natural laws and principles that defined how the world worked: the law of gravity, Bernoulli's principle, and the concepts of lift, drag, and resistance. When people then designed flying systems that recognized or harnessed the power of these laws and principles, rather than fighting them, they were finally able to fly to heights and distances that were previously unimaginable.

The objective of chapters 5 through 10 is to propose the existence of five laws or principles of disruptive technology. As in the analogy with manned flight, these laws are so strong that managers who ignore or fight them are nearly powerless to pilot their companies through a disruptive technology storm. These chapters show, however, that if managers can understand and harness these forces, rather than fight them, they can in fact succeed spectacularly when confronted with disruptive technological change. I am particularly anxious that managers read these chapters for *understanding*, rather than for simple answers. I am very confident that the great managers about whom this book is written will be very capable on their own of finding the answers that best fit their circumstances. But they must first understand what has caused those circumstances and what forces will affect the feasibility of their solutions. The following paragraphs summarize these principles and what managers can do to harness or accommodate them.

Principle #1: Companies Depend on Customers and Investors for Resources

The history of the disk drive industry shows that the established firms stayed atop wave after wave of sustaining technologies (technologies that their customers needed), while consistently stumbling over simpler disruptive ones. This evidence supports the *theory of resource dependence*.[7] Chapter 5 summarizes this theory, which states that while managers may *think* they control the flow of resources in their firms, in the end it is really customers and investors who dictate how money will be spent because companies with investment patterns that don't satisfy their customers and investors don't survive. The highest-performing companies, in fact, are those that are the best at this, that is, they have well-developed systems for killing ideas that their customers don't want. As a result, these companies find it very difficult to invest adequate resources in disruptive technologies—lower-margin opportunities that their customers don't want—until their customers want them. And by then it is too late.

Chapter 5 suggests a way for managers to align or harness this law with their efforts to confront disruptive technology. With few exceptions, the only instances in which mainstream firms have successfully established a timely position in a disruptive technology were those in which the firms' managers set up an autonomous organization charged with building a new and independent business around the disruptive technology. Such organizations, free of the power of the customers of the mainstream company, ensconce themselves among a different set of customers—those who *want* the products of the disruptive technology. In other words, companies can succeed in disruptive technologies when their managers align their organizations *with* the forces of resource dependence, rather than ignoring or fighting them.

The implication of this principle for managers is that, when faced with a threatening disruptive technology, people and processes in a mainstream organization cannot be expected to allocate freely the critical financial and human resources needed to carve out a strong position in the small, emerging market. It is very difficult for a company whose cost structure is tailored to compete in high-end markets to be profitable in low-end markets as well. Creating an independent organization, with a cost structure honed to achieve profitability at the low margins characteristic of most disruptive technologies, is the only viable way for established firms to harness this principle.

Principle #2: Small Markets Don't Solve the Growth Needs of Large Companies

Disruptive technologies typically enable new markets to emerge. There is strong evidence showing that companies entering these emerging markets early have significant first-mover advantages over later entrants. And yet, as these companies succeed and grow larger, it becomes progressively more difficult for them to enter the even newer small markets destined to become the large ones of the future.

To maintain their share prices and create internal opportunities for employees to extend the scope of their responsibilities, successful companies need to continue to grow. But while a $40 million company needs to find just $8 million in revenues to grow at 20 percent in the subsequent year, a $4 billion company needs to find $800 million in new sales. No new markets are that large. As a consequence, the larger and more successful an organization becomes, the weaker the argument that emerging markets can remain useful engines for growth.

Many large companies adopt a strategy of waiting until new markets are "large enough to be interesting." But the evidence presented in chapter 6 shows why this is not often a successful strategy.

Those large established firms that have successfully seized strong positions in the new markets enabled by disruptive technologies have done so by giving responsibility to commercialize the disruptive technology to an organization whose size matched the size of the targeted market. Small organizations can most easily respond to the opportunities for growth in a small market. The evidence is strong that formal and informal resource allocation processes make it very difficult for large organizations to focus adequate energy and talent on small markets, even when logic says they might be big someday.

Principle #3: Markets that Don’t Exist Can’t Be Analyzed

Sound market research and good planning followed by execution according to plan are hallmarks of good management. When applied to sustaining technological innovation, these practices are invaluable; they are the primary reason, in fact, why established firms led in every single instance of sustaining innovation in the history of the disk drive industry. Such reasoned approaches are feasible in dealing with sustaining technology because the size and growth rates of the markets are generally known, trajectories of technological progress have been established, and the needs of leading customers have usually been well articulated. Because the vast majority of innovations are sustaining in character, most executives have learned to manage innovation in a sustaining context, where analysis and planning were feasible.

In dealing with disruptive technologies leading to new markets, however, market researchers and business planners have consistently dismal records. In fact, based upon the evidence from the disk drive, motorcycle, and microprocessor industries, reviewed in chapter 7, the only thing we may know for sure when we read experts’ forecasts about how large emerging markets will become is that they are wrong.

In many instances, leadership in sustaining innovations—about which information is known and for which plans can be made—is not competitively important. In such cases, technology followers do about as well as technology leaders. It is in disruptive innovations, where we know least about the market, that there are such strong first-mover advantages. This is the innovator’s dilemma.

Companies whose investment processes demand quantification of market sizes and financial returns before they can enter a market get paralyzed or make serious mistakes when faced with disruptive technologies. They demand market data when none exists and make judgments based upon financial projections when neither revenues or costs can, in fact, be known. Using planning and marketing techniques that were developed to manage sustaining technologies in the very different context of disruptive ones is an exercise in flapping wings.

Chapter 7 discusses a different approach to strategy and planning that recognizes the law that the right markets, and the right strategy for exploiting them, cannot be known in advance. Called discovery-based planning, it suggests that managers assume that forecasts are wrong, rather than right, and that the strategy they have chosen to pursue may likewise be wrong. Investing and managing under such assumptions drives managers to develop plans for learning what needs to be known, a much more effective way to confront disruptive technologies successfully.

Principle #4: An Organization's Capabilities Define Its Disabilities

When managers tackle an innovation problem, they instinctively work to assign capable people to the job. But once they've found the right people, too many managers then assume that the organization in which they'll work will also be capable of succeeding at the task. And that is dangerous—because organizations have capabilities that exist independently of the people who work within them. An organization's capabilities reside in two places. The first is in its processes—the methods by which people have learned to transform inputs of labor, energy, materials, information, cash, and technology into outputs of higher value. The second is in the organization's values, which are the criteria that managers and employees in the organization use when making prioritization decisions. People are quite flexible, in that they can be trained to succeed at quite different things. An employee of IBM, for example, can quite readily change the way he or she works, in order to work successfully in a small start-up company. But processes and values are not flexible. A process that is effective at managing the design of a minicomputer, for example, would be ineffective at managing the design of a desktop personal computer. Similarly, values that cause employees to prioritize projects to develop high-margin products, cannot simultaneously accord priority to low-margin products. The very processes and values that constitute an organization's capabilities in one context, define its *dis*abilities in another context.

Chapter 8 will present a framework that can help a manager understand precisely where in his or her organization its capabilities and disabilities reside. Drawing on studies in the disk drive and computer industries, it offers tools that managers can use to create new capabilities, when the processes and values of the present organization would render it incapable of successfully addressing a new problem.

Principle #5: Technology Supply May Not Equal Market Demand

Disruptive technologies, though they initially can only be used in small markets remote from the mainstream, are disruptive because they subsequently can become fully performance-competitive within the mainstream market against established products. As depicted in Figure I.1 (on page xvi), this happens because the pace of technological progress in products frequently exceeds the rate of performance improvement that mainstream customers demand or can absorb. As a consequence, products whose features and functionality closely match market needs today often follow a trajectory of improvement by which they overshoot mainstream market needs tomorrow. And products that seriously underperform today, relative to customer expectations in mainstream markets, may become directly performance-competitive tomorrow.

Chapter 9 shows that when this happens, in markets as diverse as disk drives, accounting software, and diabetes care, the basis of competition— the criteria by which customers choose one product over another— changes. When the performance of two or more competing products has improved beyond what the market demands, customers can no longer base their choice upon which is the higher performing product. The basis of product choice often evolves from functionality to reliability, then to convenience, and, ultimately, to price.

Many students of business have described phases of the product life cycle in various ways. But chapter 9 proposes that the phenomenon in which product performance overshoots market demands is the primary mechanism driving shifts in the phases of the product life cycle.

In their efforts to stay ahead by developing competitively superior products, many companies don't realize the speed at which they are moving up-market, over-satisfying the needs of their original customers as they race the competition toward higher-performance, higher-margin markets. In doing so, they create a vacuum at lower price points into which competitors employing disruptive technologies can enter. Only those companies that carefully measure trends in how their mainstream customers *use* their products can catch the points at which the basis of competition will change in the markets they serve.

LESSONS FOR SPOTTING DISRUPTIVE THREATS AND OPPORTUNITIES

Some managers and researchers familiar with these ideas have arrived at this point in the story in an anxious state because the evidence is very strong that even the best managers have stumbled badly when their markets were invaded by disruptive technologies. Most urgently, they want to know whether their own businesses are targets for an attacking disruptive technologist and how they can defend their business against such an attack before it is too late. Others, interested in finding entrepreneurial opportunities, wonder how they can identify potentially disruptive technologies around which new companies and markets can be built.

Chapter 10 addresses these questions in a rather unconventional way. Rather than offering a checklist of questions to ask or analyses to perform, it creates a case study of a particularly vexing but well-known problem in technological innovation: the electric vehicle. Positioning myself in the role of protagonist—as the program manager responsible for electric vehicle development in a major automobile manufacturing company wrestling with the mandate of the California Air Resources Board to begin selling electric vehicles in that state—I explore the question of whether electric vehicles are in fact a disruptive technology and then suggest ways to organize this program, set its strategy, and manage it to succeed. In the spirit of all case studies, the purpose of this chapter is *not* to advance what I believe to be the correct answer to this innovator's challenge. Rather, it suggests a methodology and a way of thinking about the problem of managing disruptive technological change that should prove useful in many other contexts.

Chapter 10 thus takes us deeply into the innovator's dilemma that "good" companies often begin their descent into failure by aggressively investing in the products and services that their most profitable customers want. No automotive company is currently threatened by electric cars, and none contemplates a wholesale leap into that arena. The automobile industry is healthy. Gasoline engines have never been more reliable. Never before has such high performance and quality been available at such low prices. Indeed, aside from governmental mandates, there is no reason why we should expect the established car makers to pursue electric vehicles.

Established Technology	Disruptive Technology
Silver halide photographic film	Digital photography
Wireline telephony	Mobile telephony
Circuit-switched telecommunications networks	Packet-switched communications networks
Notebook computers	Hand-held digital appliances
Desktop personal computers	Sony Playstation II, Internet appliances
Full-service stock brokerage	On-line stock brokerage
New York & NASDAQ stock exchanges	Electronic Communications Networks (ECNs)
Full-fee underwriting of new equity and debt issues	Dutch auctions of new equity and debt issues, conducted on the Internet
Credit decisions based upon the personal judgment of bank lending officers	Automated lending decisions based upon credit scoring systems
Bricks & mortar retailing	On-line retailing
Industrial materials distributors	Internet-based sites such as Chemdex and E-steel

Printed greeting cards	Free greeting cards, downloadable over the Internet
Electric utility companies	Distributed power generation (gas turbines, micro-turbines, fuel cells)
Graduate schools of management	Corporate universities and in-house management training programs
Classroom and campus-based instruction	Distance education, typically enabled by the Internet
Standard textbooks	Custom-assembled, modular digital textbooks
Offset printing	Digital printing
Manned fighter and bomber aircraft	Unmanned aircraft
Microsoft Windows operating systems and applications software written in C++.	Internet Protocols (IP), and Java software protocols
Medical doctors	Nurse practitioners
General hospitals	Outpatient clinics and in-home patient care
Open surgery	Arthroscopic and endoscopic surgery
Cardiac bypass surgery	Angioplasty
Magnetic resonance imaging (MRI) and Computer Tomography (CT) Scanning	Ultrasound—initially floor-standing machines, ultimately portable machines

But the electric car *is* a disruptive technology and potential future threat. The innovator's task is to ensure that this innovation—the disruptive technology that doesn't make sense—is taken seriously within the company without putting at risk the needs of present customers who provide profit and growth. As chapter 10 concretely lays out, the problem can be resolved only when new markets are considered and carefully developed around new definitions of value—and when responsibility for building the business is placed within a focused organization whose size and interest are carefully aligned with the unique needs of the market's customers.

WHERE DISRUPTIONS ARE HAPPENING TODAY

One of the most gratifying aspects of my life since the first edition of *The Innovator's Dilemma* was published has been the number of people who have called, representing industries that I had never thought about, who have suggested that forces similar to those historical examples I described in these pages are disrupting their industries as well. Some of these are described in the table on the previous page. Not surprisingly, the Internet looms as an infrastructural technology that is enabling the disruption of many industries.

Each of the innovations in the right column—in the form of a new technology or a new business model—is now in the process of disrupting the established order described in the left column. Will the companies that currently lead their industries using the technologies in the left column survive these attacks? My hope is that the future might be different than the past. I believe that the future *can* be different, if managers will recognize these disruptions for what they are, and address them in a way that accounts for or harnesses the fundamental principles described in the pages that follow.

NOTES

1. John McDonald, "Sears Makes It Look Easy," *Fortune*, May, 1964, 120–121.
2. Zina Moukheiber, "Our Competitive Advantage," *Forbes*, April 12, 1993, 59.
3. Steve Weiner, "It's Not Over Until It's Over," *Forbes*, May 28, 1990, 58.
4. *Business Week*, March 24, 1986, 98.
5. Thomas J. Peters and Robert H. Waterman, *In Search of Excellence* (New York: Harper & Row, 1982).
6. *Business Week*, May 9, 1994, 26.
7. Jeffrey Pfeffer and Gerald R. Salancik, *The External Control of Organizations: A Resource Dependence Perspective* (New York: Harper & Row, 1978).

Part **One**

WHY GREAT COMPANIES CAN FAIL

CHAPTER **ONE**

How Can Great Firms Fail? Insights from the Hard Disk Drive Industry

When I began my search for an answer to the puzzle of why the best firms can fail, a friend offered some sage advice. “Those who study genetics avoid studying humans,” he noted. “Because new generations come along only every thirty years or so, it takes a long time to understand the cause and effect of any changes. Instead, they study fruit flies, because they are conceived, born, mature, and die all within a single day. If you want to understand why something happens in business, study the disk drive industry. Those companies are the closest things to fruit flies that the business world will ever see.”

Indeed, nowhere in the history of business has there been an industry like disk drives, where changes in technology, market structure, global scope, and vertical integration have been so pervasive, rapid, and unrelenting. While this pace and complexity might be a nightmare for managers, my friend was right about its being fertile ground for research. Few industries offer researchers the same opportunities for developing theories about how different types of change cause certain types of firms to succeed or fail or for testing those theories as the industry repeats its cycles of change.

This chapter summarizes the history of the disk drive industry in all its complexity. Some readers will be interested in it for the sake of history itself. [1] But the value of understanding this history is that out of its complexity emerge a few stunningly simple and consistent factors that have repeatedly determined the success and failure of the industry’s best firms. Simply put, when the best firms succeeded, they did so because they listened responsively to their customers and invested aggressively in the technology, products, and manufacturing capabilities that satisfied their customers’ next-generation needs. But, paradoxically, when the best firms subsequently failed, it was for the same reasons—they listened responsively to their customers and invested aggressively in the technology, products, and manufacturing capabilities that satisfied their customers’ next-generation needs. This is one of the innovator’s dilemmas: Blindly following the maxim that good managers should keep close to their customers can sometimes be a fatal mistake.

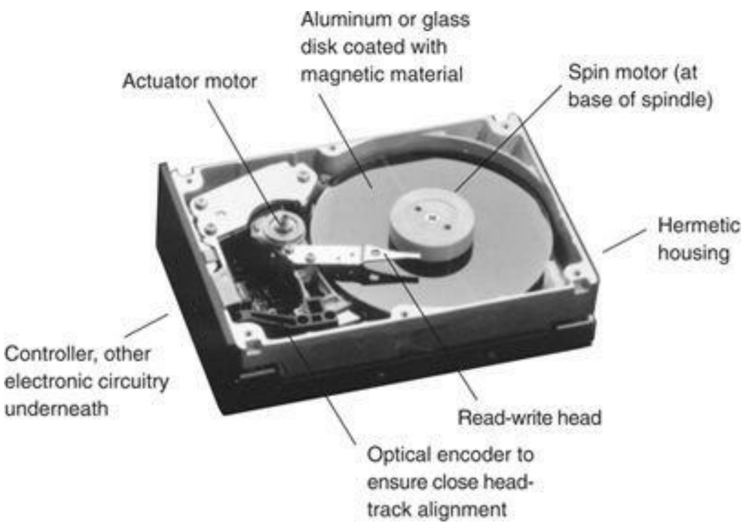
The history of the disk drive industry provides a framework for understanding when “keeping close to your customers” is good advice—and when it is not. The robustness of this framework could only be explored by researching the industry’s history in careful detail. Some of that detail is recounted here, and elsewhere in this book, in the hope that readers who are immersed in the detail of their own industries will be better able to recognize how similar patterns have affected their own fortunes and those of their competitors.

HOW DISK DRIVES WORK

Disk drives write and read information that computers use. They comprise read-write heads mounted at the end of an arm that swings over the surface of a rotating disk in much the same way that a phonograph needle and arm reach over a record; aluminum or glass disks coated with magnetic material; at least two electric motors, a spin motor that drives the rotation of the disks and an actuator motor that moves the head to the desired position over the disk; and a variety of electronic circuits that control the drive’s operation and its interface with the computer. See Figure 1.1 for an illustration of a typical disk drive.

The read-write head is a tiny electromagnet whose polarity changes whenever the direction of the electrical current running through it changes. Because opposite magnetic poles attract, when the polarity of the head becomes positive, the polarity of the area on the disk beneath the head switches to negative, and vice versa. By rapidly changing the direction of current flowing through the head’s electromagnet as the disk spins beneath the head, a sequence of positively and negatively oriented magnetic domains are created in concentric tracks on the disk’s surface. Disk drives can use the positive and negative domains on the disk as a binary numeric system—*1* and *0*—to “write” information onto disks. Drives read information from disks in essentially the opposite process: Changes in the magnetic flux fields on the disk surface induce changes in the micro current flowing through the head.

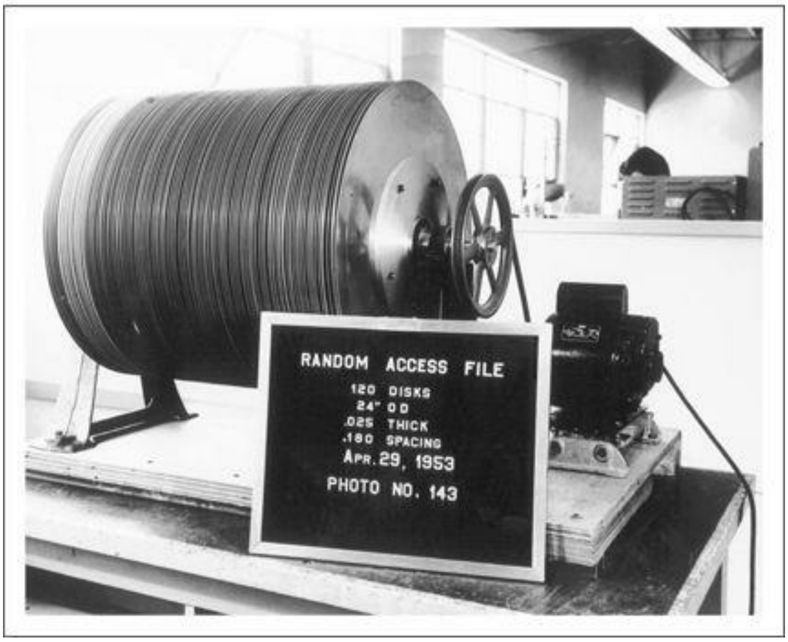
Figure 1.1 Primary Components of a Typical Disk Drive



EMERGENCE OF THE EARLIEST DISK DRIVES

A team of researchers at IBM's San Jose research laboratories developed the first disk drive between 1952 and 1956. Named RAMAC (for Random Access Method for Accounting and Control), this drive was the size of a large refrigerator, incorporated fifty twenty-four-inch disks, and could store 5 megabytes (MB) of information (see Figure 1.2). Most of the fundamental architectural concepts and component technologies that defined today's dominant disk drive design were also developed at IBM. These include its removable packs of rigid disks (introduced in 1961); the floppy disk drive (1971); and the Winchester architecture (1973). All had a powerful, defining influence on the way engineers in the rest of the industry defined what disk drives were and what they could do.

Figure 1.2 The First Disk Drive, Developed by IBM



Source: Courtesy of International Business Machines Corporation.

As IBM produced drives to meet its own needs, an independent disk drive industry emerged serving two distinct markets. A few firms developed the plug-compatible market (PCM) in the 1960s, selling souped-up copies of IBM drives directly to IBM customers at discount prices. Although most of IBM's competitors in computers (for example, Control Data, Burroughs, and Univac) were integrated vertically into the manufacture of their own disk drives, the emergence in the 1970s of smaller, nonintegrated computer makers such as Nixdorf, Wang, and Prime spawned an original equipment market (OEM) for disk drives as well. By 1976 about $1 billion worth of disk drives were produced, of which captive production accounted for 50 percent and PCM and OEM for about 25 percent each.

The next dozen years unfolded a remarkable story of rapid growth, market turbulence, and technology-driven performance improvements. The value of drives produced rose to about $18 billion by 1995. By the mid-1980s the PCM market had become insignificant, while OEM output grew to represent about three-fourths of world production. Of the seventeen firms populating the industry in 1976—all of which were relatively large, diversified corporations such as Diablo, Ampex, Memorex, EMM, and Control Data—all except IBM's disk drive operation had failed or had been acquired by 1995. During this period an additional 129 firms entered the industry, and 109 of those also failed. Aside from IBM, Fujitsu, Hitachi, and NEC, all of the producers remaining by 1996 had entered the industry as start-ups after 1976.

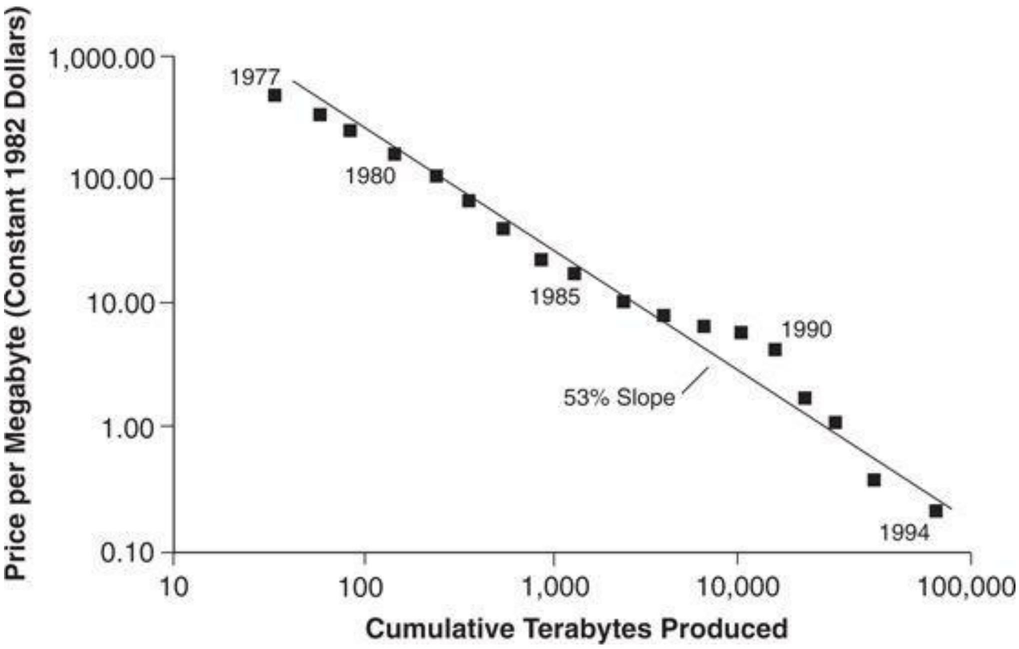
Some have attributed the high mortality rate among the integrated firms that created the industry to its nearly unfathomable pace of technological change. Indeed, the pace of change has been breathtaking. The number of megabits (Mb) of information that the industry's engineers have been able to pack into a square inch of disk surface has increased by 35 percent per year, on average, from 50 Kb in 1967 to 1.7 Mb in 1973, 12 Mb in 1981, and 1100 Mb by 1995. The physical size of the drives was reduced at a similar pace: The smallest available 20 MB drive shrank from 800 cubic inches (in. 3) in 1978 to 1.4 in. 3 by 1993—a 35 percent annual rate of reduction.

Figure 1.3 shows that the slope of the industry's experience curve (which correlates the cumulative number of terabytes (one thousand gigabytes) of disk storage capacity shipped in the industry's history to the constant-dollar price per megabyte of memory) was 53 percent—meaning that with each doubling of cumulative terabytes shipped, cost per megabyte fell to 53 percent of its former level. This is a much steeper rate of price decline than the 70 percent slope observed in the markets for most other microelectronics products. The price per megabyte has declined at about 5 percent per *quarter* for more than twenty years.

THE IMPACT OF TECHNOLOGICAL CHANGE

My investigation into why leading firms found it so difficult to stay atop the disk drive industry led me to develop the "technology mudslide hypothesis": Coping with the relentless onslaught of technology change was akin to trying to climb a mudslide raging down a hill. You have to scramble with everything you've got to stay on top of it, and if you ever once stop to catch your breath, you get buried.

Figure 1.3 Disk Drive Price Experience Curve



Source: Data are from various issues of *Disk/Trend Report*.

To test this hypothesis, I assembled and analyzed a database consisting of the technical and performance specifications of every model of disk drive introduced by every company in the world disk drive industry for each of the years between 1975 and 1994. [2] This database enabled me to identify the firms that led in introducing each new technology; to trace how new technologies were diffused through the industry over time; to see which firms led and which lagged; and to measure the impact each technological innovation had on capacity, speed, and other parameters of disk drive performance. By carefully reconstructing the history of each technological change in the industry, the changes that catapulted entrants to success or that precipitated the failure of established leaders could be identified.

This study led me to a very different view of technology change than the work of prior scholars on this question had led me to expect. Essentially, it revealed that neither the pace nor the difficulty of technological change lay at the root of the leading firms' failures. The technology mudslide hypothesis was wrong.

The manufacturers of most products have established a trajectory of performance improvement over time. [3] Intel, for example, pushed the speed of its microprocessors ahead by about 20 percent per year, from its 8 megahertz (MHz) 8088 processor in 1979 to its 133 MHz Pentium chip in 1994. Eli Lilly and Company improved the purity of its insulin from 50,000 impure parts per million (ppm) in 1925 to 10 ppm in 1980, a 14 percent annual rate of improvement. When a measurable trajectory of improvement has been established, determining whether a new technology is likely to improve a product's performance relative to earlier products is an unambiguous question.

But in other cases, the impact of technological change is quite different. For instance, is a notebook computer better than a mainframe? This is an ambiguous question because the notebook computer established a completely new performance trajectory, with a definition of performance that differs substantially from the way mainframe performance is measured. Notebooks, as a consequence, are generally sold for very different uses.

This study of technological change over the history of the disk drive industry revealed two types of technology change, each with very different effects on the industry's leaders. Technologies of the first sort *sustained* the industry's rate of improvement in product performance (total capacity and recording density were the two most common measures) and ranged in difficulty from incremental to radical. The industry's dominant firms always led in developing and adopting these technologies. By contrast, innovations of the second sort *disrupted* or redefined performance trajectories—and consistently resulted in the failure of the industry's leading firms. [4]

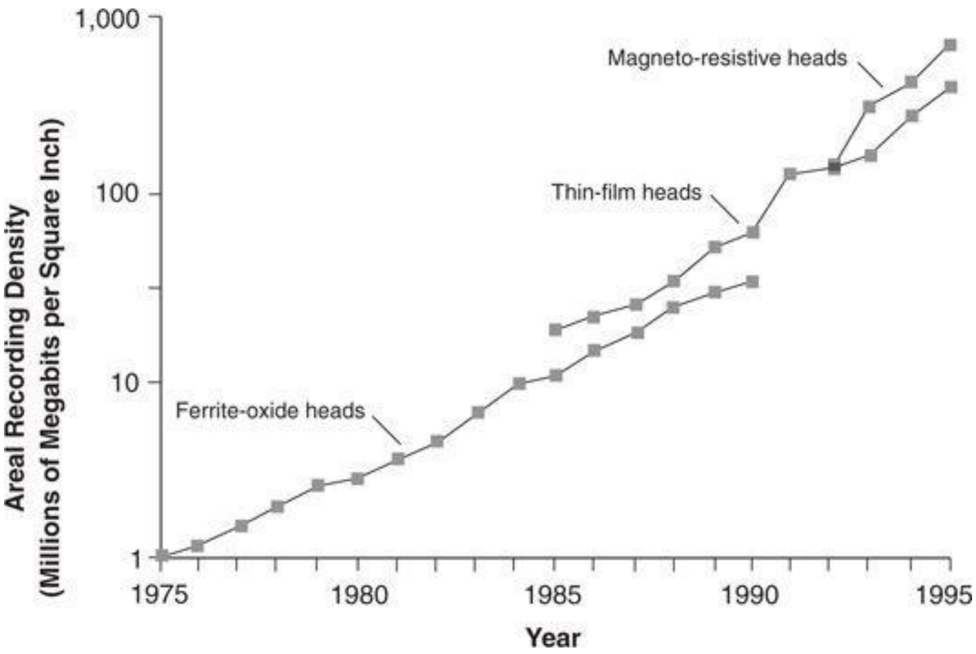
The remainder of this chapter illustrates the distinction between sustaining and disruptive technologies by describing prominent examples of each and summarizing the role these played in the industry's development. This discussion focuses on differences in how established firms came to lead or lag in developing and adopting new technologies, compared with entrant firms. To arrive at these examples, each new technology in the industry was examined. In analyzing which firms led and lagged at each of these points of change, I defined *established firms* to be those that had been established in the industry prior to the advent of the technology in question, practicing the prior technology. I defined *entrant firms* as those that were new to the industry at that point of technology change. Hence, a given firm would be considered an entrant at one specific point in the industry's history, for example, at the emergence of the 8-inch drive. Yet the same firm would be considered an established firm when technologies that emerged subsequent to the firm's entry were studied.

SUSTAINING TECHNOLOGICAL CHANGES

In the history of the disk drive industry, most technology changes have sustained or reinforced established trajectories of product performance improvement. Figure 1.4, which compares the average recording density of drives that employed successive generations of head and disk technologies, maps an example of this. The first curve plots the density of drives that used conventional particulate oxide disk technology and ferrite head technology; the second charts the average density of drives that used new-technology thin-film heads and disks; the third marks the improvements in density achievable with the latest head technology, magneto-resistive heads. [5]

The way such new technologies as these emerge to surpass the performance of the old resembles a series of intersecting technology S-curves. [6] Movement along a given S-curve is generally the result of incremental improvements within an existing technological approach, whereas jumping onto the next technology curve implies adopting a radically new technology. In the cases measured in Figure 1.4, 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, led to the improvements in density from 1 to 20 megabits per square inch (Mbpsi) between 1976 and 1989. As S-curve theory would predict, the improvement in recording density obtainable with ferrite/ oxide technology began to level off toward the end of the period, suggesting a maturing technology. The thin-film head and disk technologies' effect on the industry sustained performance improvement at its historical rate. Thin-film heads were barely established in the early 1990s, when even more advanced magneto-resistive head technology emerged. The impact of magneto-resistive technology sustained, or even accelerated, the rate of performance improvement.

Figure 1.4 Impact of New Read-Write Head Technologies in Sustaining the Trajectory of Improvement in Recording Density



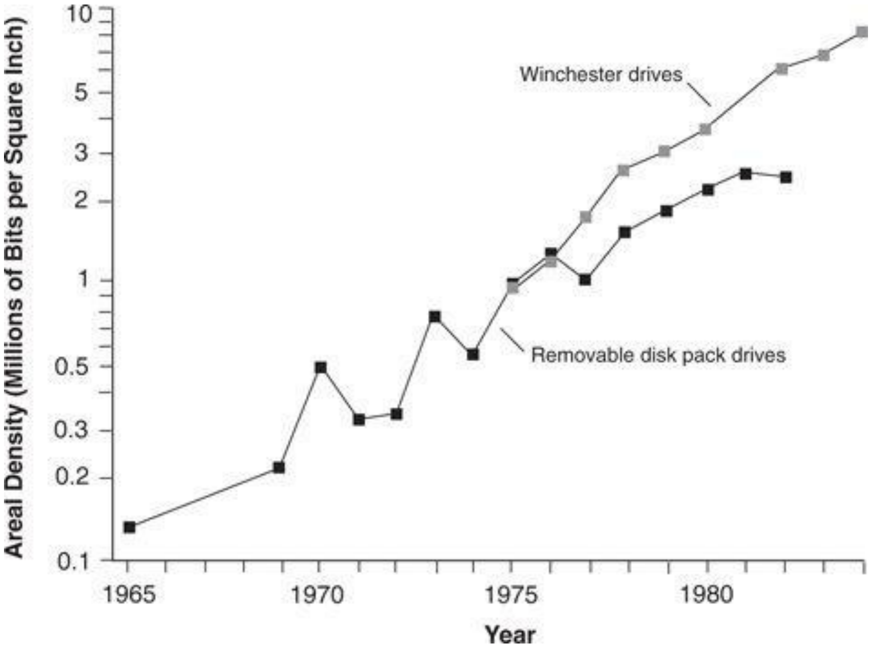
Source: Data are from various issues of *Disk/Trend Report*.

Figure 1.5 describes a sustaining technological change of a very different character: an innovation in product architecture, in which the 14-inch Winchester drive is 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 sustained the historically established rate of performance improvement. Similar graphs could be constructed for most other technological innovations in the industry, such as embedded servo systems, RLL and PRML recording codes, higher RPM motors, and embedded interfaces. Some of these were straightforward technology improvements; others were radical departures. But all had a similar impact on the industry: They helped manufacturers to sustain the rate of historical performance improvement that their customers had come to expect. [7]

In literally every case of sustaining technology change in the disk drive industry, established firms led in development and commercialization. The emergence of new disk and head technologies illustrates this.

In the 1970s, some manufacturers sensed that they were reaching the limit on the number of bits of information they could pack onto oxide disks. In response, disk drive manufacturers began studying ways of applying super-thin films of magnetic metal on aluminum to sustain the historical rate of improvements in recording density. The use of thin-film coatings was then highly developed in the integrated circuit industry, but its application to magnetic disks still presented substantial challenges. Experts estimate that the pioneers of thin-film disk technology—IBM, Control Data, Digital Equipment, Storage Technology, and Ampex—each took more than eight years and spent more than $50 million in that effort. Between 1984 and 1986, about two-thirds of the producers active in 1984 introduced drives with thin-film disks. The overwhelming majority of these were established industry incumbents. Only a few entrant firms attempted to use thin-film disks in their initial products, and most of those folded shortly after entry.

Figure 1.5 Sustaining Impact of the Winchester Architecture on the Recording Density of 14-inch Disk Drives



Source: Data are from various issues of *Disk/Trend Report*.

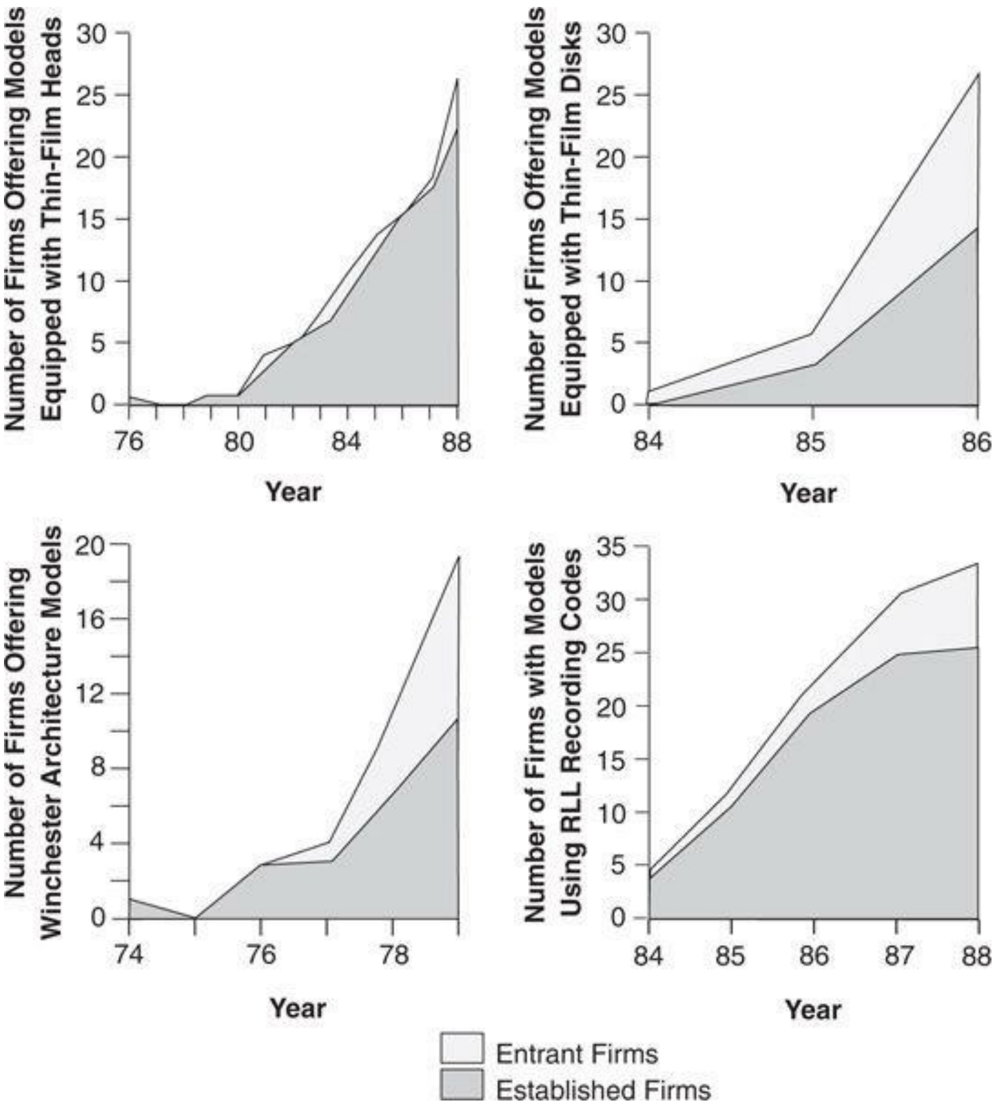
The same pattern was apparent in the emergence of thin-film heads. Manufacturers of ferrite heads saw as early as 1965 the approaching limit to improvements in this technology; by 1981 many believed that the limits of precision would soon be reached. Researchers turned to thin-film technology, produced by sputtering thin films of metal on the recording head and then using photolithography to etch much finer electromagnets than could be attained with ferrite technology. Again, this proved extraordinarily difficult. Burroughs in 1976, IBM in 1979, and other established firms first successfully incorporated thin-film heads in disk drives. In the period between 1982 and 1986, during which some sixty firms entered the rigid disk drive industry, only four (all commercial failures) attempted to do so using thin-film heads in their initial products as a source of performance advantage. All other entrant firms—even aggressively performance-oriented firms such as Maxtor and Conner Peripherals—found it preferable to learn their way using conventional ferrite heads first, before tackling thin-film technology.

As was the case with thin-film disks, the introduction of thin-film heads entailed the sort of sustained investment that only established firms could handle. IBM and its rivals each spent more than $100 million developing thin-film heads. The pattern was repeated in the next-generation magneto-resistive head technology: The industry's largest firms—IBM, Seagate, and Quantum—led the race.

The established firms were the leading innovators not just in developing risky, complex, and expensive component technologies such as thin-film heads and disks, but in *literally every other one of the sustaining innovations in the industry's history.* Even in relatively simple innovations, such as RLL recording codes (which took the industry from double-to triple-density disks), established firms were the successful pioneers, and entrant firms were the technology followers. This was also true for those architectural innovations—for example, 14-inch and 2.5-inch Winchester drives— whose impact was to sustain established improvement trajectories. Established firms beat out the entrants.

Figure 1.6 summarizes this pattern of technology leadership among established and entrant firms offering products based on new sustaining technologies during the years when those technologies were emerging. The pattern is stunningly consistent. Whether the technology was radical or incremental, expensive or cheap, software or hardware, component or architecture, competenceenhancing or competence-destroying, the pattern was the same. When faced with sustaining technology change that gave existing customers something more and better in what they wanted, the leading practitioners of the prior technology led the industry in the development and adoption of the new. Clearly, the leaders in this industry did not fail because they became passive, arrogant, or risk-averse or because they couldn't keep up with the stunning rate of technological change. My technology mudslide hypothesis wasn't correct.

Figure 1.6 Leadership of Established Firms in Sustaining Technologies



Source: Data are from various issues of *Disk/Trend Report*.

FAILURE IN THE FACE OF DISRUPTIVE TECHNOLOGICAL CHANGES

Most technological change in the disk drive industry has consisted of sustaining innovations of the sort described above. In contrast, there have been only a few of the other sort of technological change, called disruptive technologies. These were the changes that toppled the industry's leaders.

The most important disruptive technologies were the architectural innovations that shrunk the size of the drives—from 14-inch diameter disks to diameters of 8, 5.25, and 3.5-inches and then from 2.5 to 1.8 inches. Table 1.1 illustrates the ways these innovations were disruptive. Based on 1981 data, it compares the attributes of a typical 5.25-inch drive, a new architecture that had been in the market for less than a year, with those of a typical 8-inch drive, which at that time was the standard drive used by minicomputer manufacturers. Along the dimensions of performance 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 perceived needs of minicomputer manufacturers at that time. On the other hand, the 5.25-inch drive had features that appealed to the desktop personal computer market segment just emerging in the period between 1980 and 1982. It was small and lightweight, and, priced at around $2,000, it could be incorporated into desktop machines economically.

Generally disruptive innovations were technologically straightforward, consisting of off-the-shelf components put together in a product architecture that was often simpler than prior approaches. [8] They offered less of what customers in established markets wanted and so could rarely be initially employed there. They offered a different package of attributes valued only in emerging markets remote from, and unimportant to, the mainstream.

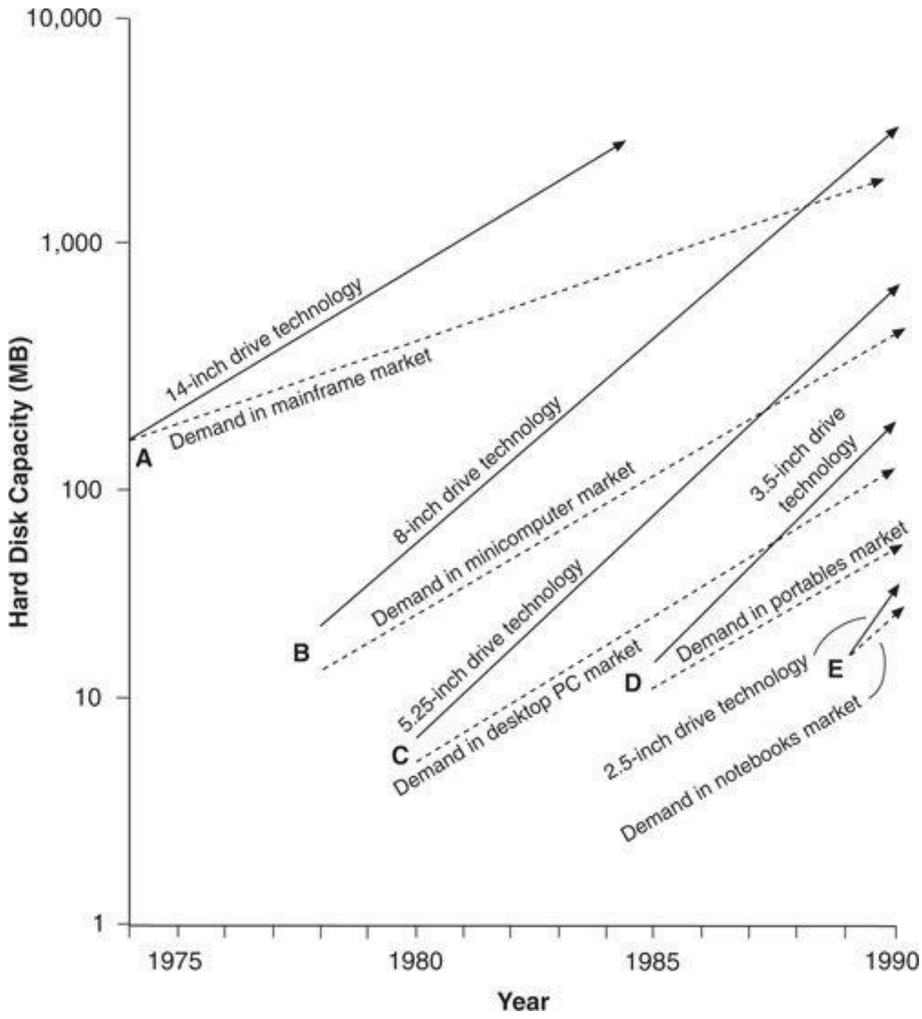
The trajectory map in Figure 1.7 shows how this series of simple but disruptive technologies proved to be the undoing of some very aggressive, astutely managed disk drive companies. Until the mid-1970s, 14-inch drives with removable packs of disks accounted for nearly all disk drive sales. The 14-inch Winchester architecture then emerged to sustain the trajectory of recording density improvement. Nearly all of these drives (removable disks and Winchesters) were sold to mainframe computer manufacturers, and the same companies that led the market in disk pack drives led the industry's transition to the Winchester technology.

Table 1.1 A Disruptive Technology Change: The 5.25-inch Winchester Disk Drive (1981)

Attribute	8-Inch Drives (Minicomputer Market)	5.25-Inch Drives (Desktop Computer Market)
Capacity (megabytes)	60	10
Physical volume (cubic inches)	566	150
Weight (pounds)	21	6
Access time (milliseconds)	30	160
Cost per megabyte	$50	$200
Unit cost	$3000	$2000

Source: Data are from various issues of *Disk/Trend Report*.

Figure 1.7 Intersecting Trajectories of Capacity Demanded versus Capacity Supplied in Rigid Disk Drives



Source: Clayton M. Christensen, "The Rigid Disk Drive Industry: A History of Commercial and Technological Turbulence," Business History Review 67, no. 4 (Winter 1993): 559. Reprinted by permission.

The trajectory map shows that the hard disk capacity provided in the median priced, typically configured mainframe computer system in 1974 was about 130 MB per computer. This increased at a 15 percent annual rate over the next fifteen years—a trajectory representing the disk capacity demanded by the typical users of new mainframe computers. At the same time, the capacity of the average 14-inch drive introduced for sale each year increased at a faster, 22 percent rate, reaching beyond the mainframe market to the large scientific and supercomputer markets. [9]

Between 1978 and 1980, several entrant firms—Shugart Associates, Micropolis, Priam, and Quantum—developed smaller 8-inch drives with 10, 20, 30, and 40 MB capacity. These drives were of no interest to mainframe computer manufacturers, which at that time were demanding drives with 300 to 400 MB capacity. These 8-inch entrants therefore sold their disruptive drives into a new application—minicomputers. [10] The customers—Wang, DEC, Data General, Prime, and Hewlett-Packard—did not manufacture mainframes, and their customers often used software substantially different from that used in mainframes. These firms hitherto had been unable to offer disk drives in their small, desk-side minicomputers because 14-inch models were too big and expensive. Although initially the cost per megabyte of capacity of 8-inch drives was higher than that of 14-inch drives, these new customers were willing to pay a premium for other attributes that were important to them—

especially smaller size. Smallness had little value to mainframe users.

Once the use of 8-inch drives became established in minicomputers, the hard disk capacity shipped with the median-priced minicomputer grew about 25 percent per year: a trajectory determined by the ways in which minicomputer owners learned to use their machines. At the same time, however, the 8-inch drive makers found that, by aggressively adopting sustaining innovations, they could increase the capacity of their products at a rate of more than 40 percent per year—nearly double the rate of increase demanded by their original "home" minicomputer market. In consequence, by the mid-1980s, 8-inch drive makers were able to provide the capacities required for lower-end mainframe computers. Unit volumes had grown significantly so that the cost per megabyte of 8-inch drives had declined below that of 14-inch drives, and other advantages became apparent: For example, the same percentage mechanical vibration in an 8-inch drive, as opposed to a 14-inch drive, caused much less variance in the absolute position of the head over the disk. Within a three-to-four-year period, therefore, 8-inch drives began to invade the market above them, substituting for 14-inch drives in the lower-end mainframe computer market.

As the 8-inch products penetrated the mainframe market, the established manufacturers of 14-inch drives began to fail. Two-thirds of them never introduced an 8-inch model. The one-third that introduced 8-inch models did so about two years behind the 8-inch entrant manufacturers. Ultimately, every 14-inch drive maker was driven from the industry. [11]

The 14-inch drive makers were not toppled by the 8-inch entrants because of technology. The 8-inch products generally incorporated standard off-the-shelf components, and when those 14-inch drive makers that did introduce 8-inch models got around to doing so, their products were very performance-competitive in capacity, areal density, access time, and price per megabyte. The 8-inch models introduced by the established firms in 1981 were nearly identical in performance to the average of those introduced that year by the entrant firms. In addition, the rates of improvement in key attributes (measured between 1979 and 1983) were stunningly similar between established and entrant firms. [12]

Held Captive by Their Customers

Why were the leading drive makers unable to launch 8-inch drives until it was too late? Clearly, they were technologically capable of producing these drives. Their failure resulted from delay in making the strategic commitment to enter the emerging market in which the 8-inch drives initially could be sold. Interviews with marketing and engineering executives close to these companies suggest that the established 14-inch drive manufacturers were held captive by customers. Mainframe computer manufacturers did not need an 8-inch drive. In fact, they explicitly did not want it: they wanted drives with increased capacity at a lower cost per megabyte. The 14-inch drive manufacturers were listening and responding to their established customers. And their customers—in a way that was not apparent to either the disk drive manufacturers or their computer-making customers—were pulling them along a trajectory of 22 percent capacity growth in a 14-inch platform that would ultimately prove fatal. [13]

Figure 1.7 maps the disparate trajectories of performance improvement demanded in the computer product segments that emerged later, compared to the capacity that changes in component technology and refinements in system design made available within each successive architecture. The solid lines emanating from points A, B, C, D, and E measure the disk drive capacity provided with the median-priced computer in each category, while the dotted lines from the same points measure the average capacity of all disk drives introduced for sale in each architecture, for each year. These transitions are briefly described below.

The Advent of the 5.25-inch Drive

In 1980, Seagate Technology introduced 5.25-inch disk drives. Their capacities of 5 and 10 MB were of no interest to minicomputer manufacturers, who were demanding drives of 40 and 60 MB from their suppliers. Seagate and other firms that entered with 5.25-inch drives in the period 1980 to 1983 (for example, Miniscribe, Computer Memories, and International Memories) had to pioneer new applications for their products and turned primarily to desktop personal computer makers. By 1990, the use of hard drives in desktop computers was an obvious application for magnetic recording. It was not at all clear in 1980, however, when the market was just emerging, that many people could ever afford or use a hard drive on the desktop. The early 5.25-inch drive makers found this application (one might even say that they *enabled* it) by trial and error, selling drives to whomever would buy them.

Once the use of hard drives was established in desktop PCs, the disk capacity shipped with the median-priced machine (that is, the capacity demanded by the general PC user) increased about 25 percent per year. Again, the technology improved at nearly twice the rate demanded in the new market: The capacity of new 5.25-inch drives increased about 50 percent per year between 1980 and 1990. As in the 8-inch for 14-inch substitution, the first firms to produce 5.25-inch drives were entrants; on average, established firms lagged behind entrants by two years. By 1985, only half of the firms producing 8-inch drives had introduced 5.25-inch models. The other half never did.

Growth in the use of 5.25-inch drives occurred in two waves. The first followed creation of a new application for rigid disk drives: desktop computing, in which product attributes such as physical size, relatively unimportant in established applications, were highly valued. The second wave followed substitution of 5.25-inch disks for larger drives in established minicomputer and mainframe computer markets, as the rapidly increasing capacity of 5.25-inch drives intersected the more slowly growing trajectories of capacity demanded in these markets. Of the four leading 8-inch drive makers —Shugart Associates, Micropolis, Priam, and Quantum—only Micropolis survived to become a significant manufacturer of 5.25-inch drives, and that was accomplished only with Herculean managerial effort, as described in chapter 5.

The Pattern Is Repeated: The Emergence of the 3.5-inch Drive

The 3.5-inch drive was first developed in 1984 by Rodime, a Scottish entrant. Sales of this architecture were not significant, however, until Conner Peripherals, a spinoff of 5.25-inch drive makers Seagate and Miniscribe, started shipping product in 1987. Conner had developed a small, lightweight drive architecture that was much more rugged than its 5.25-inch ancestors. It handled electronically functions that had previously been managed with mechanical parts, and it used microcode to replace functions that had previously been addressed electronically. Nearly all of Conner's first year revenues of $113 million [14] came from Compaq Computer, which had aided Conner's start-up with a $30 million investment. The Conner drives were used primarily in a new application—portable and laptop machines, in addition to "small footprint" desktop models—where customers were willing to accept lower capacities and higher costs per megabyte to get lighter weight, greater ruggedness, and lower power consumption.

Seagate engineers were not oblivious to the coming of the 3.5-inch architecture. Indeed, in early 1985, less than one year after Rodime introduced the first 3.5-inch drive and two years *before* Conner Peripherals started shipping its product, Seagate personnel showed working 3.5-inch prototype drives to customers for evaluation. The initiative for the new drives came from Seagate's engineering organization. Opposition to the program came primarily from the marketing organization and Seagate's executive team; they argued that the market wanted higher capacity drives at a lower cost per megabyte and that 3.5-inch drives could never be built at a lower cost per megabyte than 5.25-inch drives.

Seagate's marketers tested the 3.5-inch prototypes with customers in the desktop computing market it already served—manufacturers like IBM, and value-added resellers of full-sized desktop computer systems. Not surprisingly, they indicated little interest in the smaller drive. They were looking for capacities of 40 and 60 megabytes for their next-generation machines, while the 3.5-inch architecture could provide only 20 MB—and at higher costs. [15]

In response to lukewarm reviews from customers, Seagate's program manager lowered his 3.5-inch sales estimates, and the firm's executives canceled the program. Their reasoning? The markets for 5.25-inch products were larger, and the sales generated by spending the engineering effort on new 5.25-inch products would create greater revenues for the company than would efforts targeted at new 3.5-inch products.

In retrospect, it appears that Seagate executives read the market—at least their own market—very accurately. With established applications and product architectures of their own, such as the IBM XT and AT, these customers saw no value in the improved ruggedness or the reduced size, weight, and power consumption of 3.5-inch products.

Seagate finally began shipping 3.5-inch drives in early 1988—the same year in which the performance trajectory of 3.5-inch drives (shown in Figure 1.7) intersected the trajectory of capacity demanded in desktop computers. By that time, the industry had shipped, cumulatively, nearly $750 million in 3.5-inch products. Interestingly, according to industry observers, as of 1991 almost none of Seagate's 3.5-inch products had been sold to manufacturers of portable/laptop/notebook computers. In other words, Seagate's primary customers were still desktop computer manufacturers, and many of its 3.5-inch drives were shipped with frames for mounting them in computers designed for 5.25-inch drives.

The fear of cannibalizing sales of existing products is often cited as a reason why established firms delay the introduction of new technologies. As the Seagate-Conner experience illustrates, however, if new technologies enable new market applications to emerge, the introduction of new technology may not be inherently cannibalistic. But when established firms wait until a new technology has become commercially mature in its new applications and launch their own version of the technology only in response to an attack on their home markets, the fear of cannibalization can become a self-fulfilling prophecy.

Although we have been looking at Seagate's response to the development of the 3.5-inch drive architecture, its behavior was not atypical; by 1988, only 35 percent of the drive manufacturers that had established themselves making 5.25-inch products for the desktop PC market had introduced 3.5-inch drives. Similar to earlier product architecture transitions, the barrier to development of a competitive 3.5-inch product does not appear to have been engineering-based. As in the 14-to 8-inch transition, the new-architecture drives introduced by the incumbent, established firms during the transitions from 8 to 5.25 inches and from 5.25 to 3.5 inches were fully performance-competitive with those of entrant drives. Rather, the 5.25-inch drive manufacturers seem to have been misled by their customers, notably IBM and its direct competitors and resellers, who themselves seemed as oblivious as Seagate to the potential benefits and possibilities of portable computing and the new disk drive architecture that might facilitate it.

Prairietek, Conner, and the 2.5-inch Drive

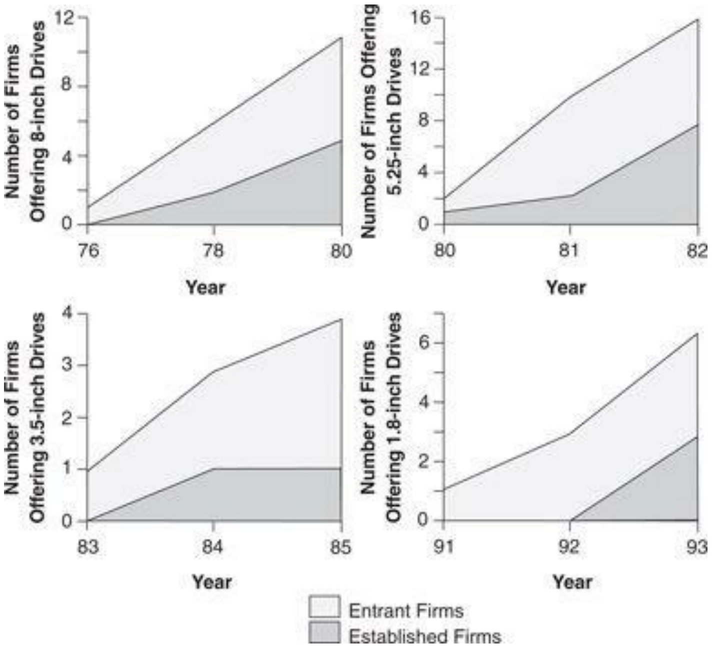
In 1989 an industry entrant in Longmont, Colorado, Prairietek, upstaged the industry by announcing a 2.5-inch drive, capturing nearly all $30 million of this nascent market. But Conner Peripherals announced its own 2.5-inch product in early 1990 and by the end of that year had claimed 95 percent of the 2.5-inch drive market. Prairietek declared bankruptcy in late 1991, by which time each of the other 3.5-inch drivemakers— Quantum, Seagate, Western Digital, and Maxtor—had introduced 2.5-inch drives of their own.

What had changed? Had the incumbent leading firms finally learned the lessons of history? Not really. Although Figure 1.7 shows the 2.5-inch drive had significantly less capacity than the 3.5-inch drives, the portable computing markets into which the smaller drives were sold valued *other* attributes: weight, ruggedness, low power consumption, small physical size, and so on. Along *these* dimensions, the 2.5-inch drive offered improved performance over that of the 3.5-inch product: It was a *sustaining* technology. In fact, the computer makers who bought Conner's 3.5-inch drive—laptop computer manufacturers such as Toshiba, Zenith, and Sharp—were the leading makers of notebook computers, and these firms needed the smaller 2.5-inch drive architecture. Hence, Conner and its competitors in the 3.5-inch market followed their customers seamlessly across the transition to 2.5-inch drives.

In 1992, however, the 1.8-inch drive emerged, with a distinctly disruptive character. Although its story will be recounted in detail later, it suffices to state here that by 1995, it was *entrant* firms that controlled 98 percent of the $130 million 1.8-inch drive market. Moreover, the largest initial market for 1.8-inch drives wasn't in computing at all. It was in portable heart monitoring devices!

Figure 1.8 summarizes this pattern of entrant firms' leadership in disruptive technology. It shows, for example, that two years after the 8-inch drive was introduced, two-thirds of the firms producing it (four of six), were entrants. And, two years after the first 5.25-inch drive was introduced, 80 percent of the firms producing these disruptive drives were entrants.

Figure 1.8 Leadership of Entrant Firms in Disruptive Technology



Source: Data are from various issues of *Disk/Trend Report*.

SUMMARY

There are several patterns in the history of innovation in the disk drive industry. The first is that the disruptive innovations were technologically straightforward. They generally packaged known technologies in a unique architecture and enabled the use of these products in applications where magnetic data storage and retrieval previously had not been technologically or economically feasible.

The second pattern is that the purpose of advanced technology development in the industry was always to *sustain* established trajectories of performance improvement: to reach the higher-performance, higher-margin domain of the upper right of the trajectory map. Many of these technologies were radically new and difficult, but they were not disruptive. The customers of the leading disk drive suppliers led them toward these achievements. Sustaining technologies, as a result, did not precipitate failure.

The third pattern shows that, despite the established firms' technological prowess in leading sustaining innovations, from the simplest to the most radical, the firms that led the industry in every instance of developing and adopting disruptive technologies were entrants to the industry, not its incumbent leaders.

This book began by posing a puzzle: Why was it that firms that 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 the problem established firms seem unable to confront successfully is that of *downward* vision and mobility, in terms of the trajectory map. Finding new applications and markets for these new products seems to be a capability that each of these firms exhibited once, upon entry, and then apparently lost. It was as if the leading firms were held captive by their customers, enabling attacking entrant firms to topple the incumbent industry leaders each time a disruptive technology emerged.[16] Why this happened, and is still happening, is the subject of the next chapter.

APPENDIX 1.1:
A NOTE ON THE DATA AND METHOD USED TO GENERATE FIGURE 1.7

The trajectories mapped in Figure 1.7 were calculated as follows. Data on the capacity provided with computers was obtained from *Data Sources*, an annual publication listing the technical specifications of all computer models available from every computer manufacturer. For instances in which particular models were available with different features and configurations, the manufacturer provided *Data Sources* with a "typical" system configuration with defined random access memory (RAM) capacity, performance specifications of peripheral equipment (including disk drives), list prices, and year of introduction. For instances in which a given computer model was offered for sale over a sequence of years, the hard disk capacity provided in the typical configuration typically increased. *Data Sources* used the categories mainframe, mini/midrange, desktop personal, portable and laptop, and notebook. As of 1993, 1.8-inch drives were not being used in hand-held computers, so no data on that potential market existed.

For Figure 1.7, for each year and each class of computers, all models available for sale were ranked by price and the hard disk capacity provided with the median-priced model identified. The best-fit lines through the resultant time series were plotted as the solid lines in Figure 1.7 for expository simplification to indicate the trend in typical machines. In reality, of course, there is a wide band around these lines. The *frontier* of performance—the highest capacity offered with the most expensive computers—was substantially higher than the typical values shown.

The dotted lines in Figure 1.7 represent the best-fit line through the unweighted average capacity of all disk drives introduced for sale in each given architecture for each year. This data was 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 frontier or 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. The upper and lower bands around the median and average figures shown in Figure 1.7 are generally parallel to the lines shown.

Because higher capacity drives were available in the market than were offered with the median-priced systems, the solid-line trajectories in Figure 1.7, as I state in the text, represent the capacities "demanded" in each market. In other words, the capacity per machine was not constrained by technological availability. Rather, it represents the selection of hard disk capacity by computer users, given the prevailing cost.

NOTES

1. A more complete history of the disk drive industry can be found in Clayton M. Christensen, "The Rigid Disk Drive Industry: A History of Commercial and Technological Turbulence," *Business History Review* (67), Winter, 1993, 531–588. This history focuses only on the manufacturers of rigid disk drives or hard drives—products on which data are stored on rigid metal platters. Companies manufacturing floppy disk drives (removable diskettes of flexible mylar coated with iron oxide on which data are stored) historically were different firms from those making hard disk drives.
2. Much of the data for this analysis came from *Disk/Trend Report*, a highly respected annual market research publication, augmented with more detailed product-specification sheets obtained from the disk drive manufacturers themselves. I am grateful to the editors and staff at Disk/Trend, Inc., for their patient and generous assistance in this project.
3. The concept of trajectories of technological progress was examined by Giovanni Dosi in "Technological Paradigms and Technological Trajectories," *Research Policy* (11), 1982, 147–162.
4. The ways in which the findings of this study differ from those of some earlier scholars of technology change while building upon those of others are discussed in greater detail in chapter 2.
5. The first technology for making heads built an electromagnet by wrapping a fine thread of copper wire around a core of iron oxide (ferrite); hence the term *ferrite head*. Incremental improvements to this approach involved learning to grind the ferrite to finer and finer dimensions, using better lapping techniques, and strengthening the ferrite by doping it with barium. *Thin-film heads* were made photolithographically, using technology similar to that used in making integrated circuits on silicon wafers to etch the electromagnet on the surface of the head. This was difficult because it involved much thicker layers of material than were common in IC manufacturing. The third technology, adopted starting in the mid-1990s, was called *magneto-resistive heads*. These were also made with thin-film photolithography, but used the principle that changes in the magnetic flux field on the disk surface changed the electrical resistivity of the circuitry in the head. By measuring changes in resistivity rather than changes in the direction of current flow, magneto-resistive heads were much more sensitive, and hence permitted denser data recording, than prior technology. In the evolution of disk technology, the earliest disks were made by coating fine needle-shaped particles of iron oxide—literally rust—over the surface of a flat, polished aluminum platter. Hence, these disks were called *oxide* disks. Incremental improvements to this technology involved making finer and finer iron oxide particles, and dispersing them more uniformly, with fewer uncoated voids on the aluminum platter's surface. This was supplanted by a sputtering technology, also borrowed from semiconductor processing, that coated the aluminum platter with a thin film of metal a few angstroms thick. The thinness of this layer; its continuous, rather than particulate nature; and the process's flexibility in depositing magnetic materials with higher coercivity, enabled denser recording on thin-film disks than was feasible on oxide disks.
6. Richard J. Foster, *Innovation: The Attacker's Advantage* (New York: Summit Books, 1986).
7. The examples of technology change presented in Figures 1.1 and 1.2 introduce some ambiguity to the unqualified term *discontinuity*, as used by Giovanni Dosi (see "Technological Paradigms and Technological Trajectories," *Research Policy* [11] 1982), Michael L. Tushman and Philip Anderson (see "Technological Discontinuities and Organizational Environments," *Administrative*

Science Quarterly [31], 1986), and others. The innovations in head and disk technology described in Figure 1.4 represent *positive* discontinuities in an established technological trajectory, while the trajectory-disrupting technologies charted in Figure 1.7 represent *negative* discontinuities. As will be shown below, established firms seemed quite capable of leading the industry over positive discontinuities, but generally lost their industry lead when faced with negative discontinuities.

8. This tendency consistently appears across a range of industries. Richard S. Rosenbloom and Clayton M. Christensen (in "Technological Discontinuities, Organizational Capabilities, and Strategic Commitments," *Industrial and Corporate Change* [3], 1994, 655–685) suggest a much broader set of industries in which leading firms may have been toppled by technologically straightforward disruptive innovations than is covered in this book.

9. A summary of the data and procedures used to generate Figure 1.7 is included in Appendix 1.1.

10. The minicomputer market was not new in 1978, but it was a new application for Winchester-technology disk drives.

11. This statement applies only to independent drive makers competing in the OEM market. Some of the vertically integrated computer makers, such as IBM, have survived across these generations with the benefit of a captive internal market. Even IBM, however, addressed the sequence of different emerging markets for disk drives by creating autonomous "start-up" disk drive organizations to address each one. Its San Jose organization focused on high-end (primarily mainframe) applications. A separate division in Rochester, MN, focused on mid-range computers and workstations. IBM created a different organization in Fujisawa, Japan, to produce drives for the desktop personal computer market.

12. This result is very different from that observed by Rebecca M. Henderson (see *The Failure of Established Firms in the Face of Technological Change: A Study of the Semiconductor Photolithographic Alignment Industry*, dissertation, Harvard University, 1988), who found the new-architecture aligners produced by the established manufacturers to be inferior in performance to those produced by entrant firms. One possible reason for these different results is that the successful entrants in the photolithographic aligner industry studied by Henderson brought to the new product a well-developed body of technological knowledge and experience developed and refined in other markets. In the case studied here, none of the entrants brought such well-developed knowledge with them. Most, in fact, were *de novo* start-ups composed of managers and engineers who had defected from established drive manufacturing firms.

13. This finding is similar to the phenomenon observed by Joseph L. Bower, who saw that explicit customer demands have tremendous power as a source of impetus in the resource allocation process: "When the discrepancy (the problem to be solved by a proposed investment) was defined in terms of cost and quality, the projects languished. In all four cases, the definition process moved toward completion when capacity to meet sales was perceived to be inadequate.… In short, pressure from the market reduces both the probability and the cost of being wrong." Although Bower specifically refers to manufacturing capacity, the same fundamental phenomenon—the power of the known needs of known customers in marshaling and directing the investments of a firm—affects response to disruptive technology. See Joseph L. Bower, *Managing the Resource Allocation Process* (Homewood, IL: Richard D. Irwin, 1970) 254.

14. In booking $113 million in revenues, Conner Peripherals set a record for booking more revenues in its first year of operation than any manufacturing company in United States history.

15. This finding is consistent with what Robert Burgelman has observed. He noted that one of the greatest difficulties encountered by corporate entrepreneurs has been finding the right "beta test

sites” where products could be interactively developed and refined with customers. Generally, a new venture’s entrée to the customer was provided by the salesperson representing the firm’s established product lines. This helped the firm develop new products for established markets but not to identify new applications for new technology. See Robert A. Burgelman and Leonard Sayles, *Inside Corporate Innovation* (New York: The Free Press, 1986) 76–80.

16. I 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 assertions about the attacker’s advantage. The historical examples Foster uses to substantiate his theory generally seem to have been disruptive innovations. See Richard J. Foster, *Innovation: The Attacker’s Advantage* (New York: Summit Books, 1986).