Strategies for Survival in Fast-Changing Industries

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Technology strategy variables tend to predominate as predictors of survival in the fast-changing rigid disk drive industry. Building on these previous studies, we here test the hypothesis that the technological and market strategies of a new entrant are highly interrelated and that their joint effect plays an important role in a firm’s probability of survival. In particular, we propose that firms that target new market segments with an architectural innovation will tend to be more successful than those that target existing markets or innovate in component technology, even after controlling for all the competing predictors of survival.

This paper advances the existing literature on innovation by tracing the main technical elements of a dominant design in the rigid disk drive industry over time, and provides a much more rigorous definition of the concept of a dominant design than we have had in the past. We find the notion of first-mover advantage is not applicable in the rigid disk drive industry. Instead, we propose the idea of an entry-window tightly linked to the emergence of the dominant product design as defined.

(Dominant Designs; Innovation; Standards; Disk Drives; Strategy; Technology)

1. Introduction

Scholars have investigated the factors affecting the survival of firms from a range of academic perspectives. One stream of research has focused on firms’ abilities to confront technological change as a primary determinant of survival (Cooper and Schendel 1976, Foster 1986). Some scholars have seen the roots of firms’ rigidities in the face of technological change in the cultures and routines that historically had led to their success (Maidique and Zirger 1984, Schein 1988, Leonard-Barton 1992). Requirements for different technological skills have also been shown to affect survival (Clark 1985, Tushman and Anderson 1986, Henderson and Clark 1990). In particular, some have noted the emergence of a dominant product design as a watershed event that drastically reduces the probabilities of success for subsequent entrants (Utterback and Abernathy 1975, Utterback and Suárez 1993, Freeman 1994, Suárez and Utterback 1995). A separate stream of research has focused on external forces that constrain managers’ abilities to change firms’ competitive and technological strategies in order to survive (Pfeffer and Salancik 1978, Willard and Cooper 1985). Some scholars in this tradition have employed the tools of population ecology to identify those forces that most powerfully affect the probabilities of survival (Hannan and Freeman 1989, Carroll and Hannan 1989).

While the findings of these researchers have sometimes seemed disjointed and even at odds with one another, some integrative studies have recently emerged that suggest how technological, cultural, managerial, and competitive forces can interact to affect firms’ probabilities of survival (Christensen and Rosenbloom 1995, Christensen and Bower 1996). Our paper builds on this integrative perspective, applying more rigorous techniques than previously have been employed to examine which factors most powerfully affect the survival of
firms. It analyzes data on the firms that constituted the rigid disk drive industry from 1975 to 1990 and suggests that the factors that seem most closely associated with survival in this industry could inform us about other fast-paced industries as well.

The conclusion that emerges most powerfully from this study is that variables related to managerial choice, rather than factors in the outside environment that are beyond the control of managers, were the primary factors driving firm survival in the disk drive industry. This overall finding is built on two insights, which we suggest could be applicable to other industries than the one studied here. The first is that the emergence of a dominant product design indeed marks a significant watershed in the competitive nature of an industry. In disk drives, firms that incorporated the key elements of what became the dominant product design in their product line had a probability of survival that was over twice that of firms that ignored the emergence of the dominant design. In addition, there appears to have been a "window of learning" or "window of opportunity" in this industry just prior to the emergence of a dominant product design, during which entry was particularly advantageous. Firms that entered many years before, in the stage of the industry's development characterized by broader variety in product architecture and low volume-per-model manufacturing, faced a higher probability of failure—which suggests that the capabilities and cultures they developed in that competitive environment might not have equipped them well for the competition that characterized the industry after the dominant design emerged.

The analytical techniques employed in this study offer a deeper insight into what constitutes a dominant product design, and into the process by which such product designs emerge, than previously has been available. The dominant design for disk drives was defined by certain architectural concepts, which came to be used by all surviving manufacturers. Within this design architecture framework, component-level innovation (much of it radical, or competence-destroying in character) continued at a furious pace long after the dominant architecture became established. Certain of these component technologies became established as standard in all products as well. Use of new components, however, did not significantly affect the probabilities of firms' survival. Hence, we propose that the elements of a dominant design that are most salient to a company's survival are architectural in character: they are the concepts that define how the components within the product interact or relate to one another (Henderson and Clark 1990).

The second insight relates to the risk of betting on new technologies versus betting on new markets. We found that in the disk drive industry, firms whose entry strategies involved using proven component technologies in products that facilitated the emergence of new market segments, had significantly higher probabilities of survival than did firms that entered established market segments with new component technologies that offered better performance. In other words, our results suggest that entry strategies that entail market risk (entering an emerging market with proven component technology) may be less risky than strategies that entail technological risk (entering an established market with new, higher-performance component technology).¹

The main hypotheses can be summarized as follows: (a) firms that adopt the dominant design features will be less likely to exit from the industry; (b) firms that enter the industry during the "window of learning" just prior to the emergence of the dominant design, will be less likely to exit; and (c) firms that introduce architectural innovations into new markets will be less likely to exit.

2. The Rigid Disk Drive Industry

Disk drives are magnetic information storage and retrieval devices used with most types of computers. The principal components of most disk drives are disks, which are substrates coated with magnetic material formatted to store information in concentric tracks; read-write heads, which are tiny electromagnets positioned...
over the spinning disks that, when energized, orient the polarity of the magnetic material on the disk immediately beneath them; a motor that drives the rotation of the disks; an actuator mechanism that positions the head precisely over the track on which data are to be read or written; and electronic circuitry and software, which control the drive's operation and enable it to communicate with the computer. These components work together within a particular product architecture. From the industry's inception there have been significant technological changes both within each component and in the architecture.

The rigid disk drive industry's history is a remarkable story of rapid growth, market turbulence, and technology-driven "creative destruction." The value of drives produced grew at a 35% annual rate between 1975 and 1989, when the worldwide market size exceeded $13 billion. Of the 17 firms that populated the industry in 1976—all of which were relatively large, diversified corporations—all had failed and exited, or had been acquired, by 1990. During this period an additional 124 firms entered the industry, and 100 of those also failed. Some 60% of the producers remaining by 1989 had entered the industry as start-ups since 1976. A host of factors contributed to this turbulence and high mortality rate, as described elsewhere (Christensen 1993). Key events that powerfully affected the fortunes of the industry's participants, however, were those that comprised the emergence of a dominant design for rigid disk drives.

Figure 1 shows the dynamics of the industry. Note from the figure that the total number of firms active in the industry increased steadily between 1976 and 1983, reaching more than 50 active firms in 1983. From there on, a "shake-out" began: during the 1983–1989 period, there was a steady decrease in the number of firms in the industry, leaving the population in 1989 at about half of what it was in 1983 (Utterback 1994). This can be confirmed by looking at the entry and exit curves in the figure; note that the entry curve lies above the exit curve for all but one year up to 1983, and that this situation is reversed for the years following 1983. As we
3. The Evolution of a Dominant Design in Rigid Disk Drives

The data-rich technological history of the rigid disk drive industry (Christensen 1992, 1993) enables a more fine-grained examination of the emergence of a dominant design than was possible in many earlier studies. (Utterback and Abernathy 1975, Utterback and Suárez 1994, Anderson and Tushman 1990). The dominant disk drive design took about 30 years to develop. As Abernathy predicted, the dominant disk drive design was not the result of IBM's initial radical innovation that created the world's first disk drive in 1956. Rather, it resulted from "the weight of many innovations that tilt(ed) the economic balance in favor of one design approach" (Abernathy 1978).

There were, specifically, four innovations that occurred between 1973 and 1986, behind which the entire industry aligned in defining the dominant disk drive design. Two of these—the Winchester architecture and intelligent interfaces—were architectural in character, involving a significant rearrangement of the ways in which the components interacted within the design (Henderson and Clark 1990). The other two were components—a rotary voice coil actuator motor and a direct-drive pancake motor positioned at the bottom of the spindle—that became a standard part of every drive. The analyses reported below show that although all four had become standard elements of 98% of all drives by 1990, the architectural technologies were those that had the strongest impact on survival probabilities.

### 3.1. The Winchester Architecture

The first step toward a dominant design occurred in 1973, when IBM introduced its first drive employing the Winchester design architecture. Prior drives generally had employed removable stacks of disks mounted on a single spindle—a design that had originally been developed to increase effective capacity of drives. When the disks were full, the disk pack could be removed and a new stack inserted. IBM's Winchester architecture sealed the entire disk drive—heads, disks, motors, bearings, and everything else—inside a dust-free housing. This enabled the heads to fly over a thousand times closer to the surface of the disk than was possible in the removable disk pack design. The resultant improvement in the recording density in Winchester drives made it immediately popular. As Table 1 shows, the percentage of all drives introduced each year that were of the Winchester design increased from 1% in 1975 to 12% in 1980 and 88% by 1985.

### 3.2. The Under-Spindle Pancake Motor

For about 10 years after the initial appearance of the Winchester architecture, the transmission mechanism for spinning the disks was a fan belt that linked an AC motor positioned in the corner of the drive’s housing with a pulley positioned at the base of the spindle. When Seagate Technology introduced its first "micro-
drive” with 5.25-inch-diameter disks in 1980, there was physically no room within the housing for such a large motor and pulley mechanism. Seagate’s solution was to place a flat “pancake” direct-drive motor under the base of the spindle, eliminating the belt and pulleys. This design quickly gained currency. Christensen (1997) shows that 43% of all drives introduced in 1982 employed pancake motors positioned beneath the spindle. This increased to 98% by 1990.

3.3. Rotary Voice Coil Actuator Motors

Disk drives require two motors: the spin motor (described above) that drives the rotation of the disks, and an actuator motor that moves the heads into position over the proper track on the disk. Most early drives employed a voice coil actuator motor that works on the same principle used in sound diaphragms of telephone handsets. As the strength of an electromagnet varies with the amount of current flowing through it, an iron bar is moved in and out, in a very precise, continuous motion. When Shugart Associates introduced its first drive in 1978, it replaced the voice-coil actuator with a less expensive stepper motor—a motor that rotated in small, discrete steps that corresponded exactly to the spacing of tracks on the disk's surface. Other manufacturers of the period experimented with other technologies as well, such as torque motors and rack and pinion gearing, in an effort to achieve the precision needed to position heads exactly over the right track on the disk, as inexpensively as possible.

By 1986 it had become clear that there were limits to the recording density achievable with stepper and torque motor actuators. The reason was that they moved the head across the disk surface in predetermined steps. The drive, in essence, had to “assume” that a new track of data would be exactly beneath the head when it took a step. Because disks could expand or contract when they changed temperature, however, this track-per-step alignment became impossible to achieve unless tracks of data on the disk were spaced sufficiently far apart. The industry ultimately had to abandon alternative motors, and it standardized on voice coil actuators, which could move in continuous increments. This permitted drive makers to build closed-loop feedback systems into the drives, so that heads could be continuously and precisely repositioned above the correct tracks as the drives expanded and contracted with temperature, were bounced and jostled, and so on. Christensen also shows that although 42% of all new drives introduced in 1982 used stepper motors, by 1987 the vast majority had reverted back to the voice coil motor. In virtually every case, drives with voice coil motors by 1987 also employed one of two methods for closed-loop feedback, that enabled the continuous repositioning of heads over desired tracks. The standardization on voice coil technology with closed-loop continuous adjustment systems contributed strongly to the industry’s ability to move from 450 concentric tracks of data per inch of disk radius achievable with stepper motors in 1983 to 4,500 tracks per inch in 1994.

A dominant mechanical design of the actuator mechanism also emerged over this period. Until 1978 the heads were inserted and withdrawn in a straight line along the radius of the disk in what was called a linear actuator design. Designers’ desire to shrink the physical size of drives made this design infeasible, however, and by 1985 a rotary design—in which the heads swung across the disk’s surface like the arm of a phonograph, with one end of the arm fixed—became standard. The linear design had essentially disappeared by 1986.

3.4. Embedded Intelligent Interface Electronics

Until 1983, the interface between most drives and their host computers was governed by a separate circuit card, often supplied to the computer manufacturer or disk drive maker by a third party. This was the year in which Quantum Corporation announced the first drive with an intelligent Small Computer Standard Interface (SCSI) control circuit, all integrated onto a single silicon chip that was embedded within the drive. Intelligent drive electronics (IDE) such as SCSI enabled an array of performance enhancements, such that no drive could be performance-competitive without them. These features included: (a) the rate at which data could be transferred to and from the computer no longer was constrained by the speed of rotation of the disks; (b) codes could be incorporated into the drive that could detect and correct errors; (c) the location of any defects on the surface of the disk could be mapped, and the drive could then be self-programmed not to store data on any defective location; and (d) the density of data could be made more consistent across the disk’s surface. Before IDE, drives
wrote data at a constant clock rate. On the rotating disk, however, the outer tracks moved beneath the heads at a much faster speed than the tracks closest to the disk’s center. As a consequence, data were written much more sparsely on the outer tracks than on the inner ones. IDE permitted drives to vary the rate at which they wrote data, to account for differences in the speed at which tracks of varying distances from the center of the disk passed beneath the head. Virtually all drives in the industry introduced after 1987 employed embedded intelligent controllers.

The emergence of a dominant design in the disk drive industry was a process that spanned a decade—it was not a discrete event. The evolution toward the dominant design, however, rapidly gained momentum in 1980, and by 1983 the first model incorporating all features of today’s dominant design had been announced. Although the four innovations comprising the dominant design were contributed by four different firms—IBM, Shugart, Seagate, and Quantum—the first model in the industry to embody all elements of the dominant disk drive design in a single model was announced in 1983 by yet a different firm, Maxtor, that had just entered the industry. Christensen (1997) shows that the rest of the industry’s design efforts coalesced around that paradigm within the few years thereafter.

Of course, innovations in disk drive technology continue at a furious pace. The architecture has shrunk dramatically, from disks that were 14 inches in diameter in 1973 to disks that are 1.8 inches today. The speed of the pancake motors has increased from 3600 revolutions per minute (rpm) in 1980 to 7200 rpm today. The technologies employed in the design and manufacture of recording heads have changed, and continue to change, dramatically; and the intelligence programmed into the drives’ controller chips has increased their reliability and speed dramatically. All these improvements, however, are achieved at the component level, within the fundamental design parameters that now constitute a dominant disk drive design.\(^2\)

\(^2\) In defining this dominant disk drive design in this way, we do not claim that this is a permanent dominant design. New technologies, combined with the demands of new markets, could in the future render the current design obsolete and lead to the emergence of another, more effective technology. In such a case, we would expect the patterns of survival and failure to repeat themselves, in the manner described below.

4. Hypotheses

Our previous work marks the starting point of the hypotheses we test in this paper. Utterback and Abernathy (1975) and Suárez and Utterback (1995) propose and give support to the idea that the survival of firms is affected by the technological evolution of the industry. In particular, they propose that the emergence of a dominant design will mark a clear milestone in the competitive landscape of an industry. The period after a dominant design is characterized by rapid decrease in the number of firms in the industry, in which many firms exit the business, because the dominant design allows for the exploitation of economies of scale and other entry barriers and competitive hurdles (see Utterback and Suárez 1993). Consistent with this argument, Suárez and Utterback found statistical support for their hypothesis that the hazard profile of pre-dominant design entrants was lower than that of post-dominant design entrants.

Indeed, the nature of competition in the disk drive industry changed dramatically after the dominant design began to coalesce in the mid-1980s. Prior to its emergence, industry volumes were less than 2 million units in 1984. By 1990 annual volumes over 25 million units had become typical. Product design cycles that averaged about 30 months prior to the advent of the dominant design got compressed to 12 months. Average cost per megabyte fell in constant dollars from about $22 in 1984 to $3.30 in 1990. And most significantly, prior to appearance of the dominant design, a host of competitors with very different manufacturing cost capabilities were able to coexist, because the lack of standardization in product features created substantial variety in market segmentation—creating niches where high-cost competitors could be relatively protected. In 1984, for example, the difference in the cost of making a 20-MB drive differed by as much as 40% between the largest and fifth largest producer. In 1990, after the dominant design had coalesced, differences between the manufacturing costs of the largest and fifth largest producers had narrowed to less than 5%. Product standardization lowered boundaries to mobility across market seg-
ments. As a consequence, price- and time-based competition had become severe (Christensen 1995).

Several authors have raised concerns about the validity of the dominant design model, particularly for new, fast-changing industries such as the disk drive industry (Teece 1986, Klepper 1996). The data available for this industry allow us to directly test the dominant design hypotheses—together with many others—as we can trace firm by firm and year by year the models produced and the technologies employed in each model. In the previous section we identified four elements of the dominant design in this industry, and we assembled data on the use of each of these four components, year by year and firm by firm. Following the logic of the dominant design framework, we hypothesize that firms that incorporated these elements of dominant design in their new products will have experienced a lower probability of failure than those that did not, even in a fast-changing industry such as disk drives.

We also hypothesize that there might be entry timing issues that are unique to fast-changing industries. Scholars who first examined the relation between entry timing and survival found that early entrants have an advantage (Foster 1986, Rosenbloom and Cusumano 1987). Previous work by Suárez and Utterback (1995) tended to support this idea, dividing data into pre- and post-dominant design entrants. Other recent research has suggested that very early entrants often fail, while somewhat later entrants are more likely to survive (Mitchell and Singh 1993). Our study of the fast-paced disk drive industry, however, allows us to go one step further. We hypothesize the existence of a “window of opportunity” or “window of learning” to enter the industry, during the period just prior to the emergence of a dominant product design. Firms that entered the industry during this short window tended to have a lower probability of failure.

The reason is that in fast-paced industries, learning—more precisely, the timing of learning—becomes critical. As the technology changes rapidly, knowledge and capabilities obsolesce more rapidly than in other industries. This implies that capabilities and knowledge gained at earlier stages in an industry’s development might not be useful—in fact, might become liabilities—in the competitive environment triggered by the emergence of a dominant design. In the disk drive industry, there appears to have been a critical period just prior to the emergence of the dominant design. Firms that entered during this period, and established the capabilities for rapid product development and volume manufacturing that came to characterize the industry, seem to have had a higher probability of survival than firms whose capabilities were defined in a different competitive environment.

Having described a window of opportunity to enter the market, our proposition is that entering earlier or later with respect to this window will be riskier, as is implied by the discussion above. Firms entering too early will miss the most attractive value network and spend resources in acquiring knowledge that might become obsolete. Firms entering too late will have to face the steep entry barriers that dominant-design producers have been able to raise, in the form of economies of scale, brand name, manufacturing experience, and so on. Our window of opportunity proposition could be seen as a departure from common wisdom on entry timing, which claims that earlier entrants have an advantage. However, we like to think of it as a “fine-tuning” of the entry timing hypothesis, which better fits the reality of fast-changing industries such as hard disk drives.

Christensen (1993) has proposed that the technological choices made by a firm when it enters the market also affects its posterior success or failure. In particular, and building on Henderson and Clark (1990), he shows that firms entering the disk drive industry based on an architectural innovation tended to perform much better than those which entered the market based on component innovation. He then notices that most of the architectural innovators in the disk drive industry made their entry into new markets instead of established ones. Entry into new markets allows them to avoid direct competition with established firms and make progress in the new market segment until they were strong enough to defy the established firms in the established markets.

This is consistent with the findings of Mitchell and Singh (1993).

Building on these previous studies, we here test the hypothesis that the technological and market strategies of a new entrant are highly interrelated and that their joint effect plays an important role in a firm’s probability of survival. In particular, we propose that firms that
target new market segments with an architectural innovation will tend to be more successful than those that target existing markets or innovate in component technology, even after controlling for all the competing predictors of survival.

We stress the fact that all of the technology strategy hypotheses described above should complement, not replace, other alternative explanations of survival, such as the population ecology and standard economic or management approaches; indeed, as we will see below, we test for many of these alternative approaches in this paper. The relative importance of each approach to firm survival will change depending on the industry under study. Although we lack sufficient data from different industries to prove it, we are inclined to believe that in modern, fast-changing industries, technology strategy variables tend to predominate when it comes to explaining firm survival. As we will see, the rigid disk drive industry is a case in point.

5. Data
The data used in this study were taken from Disk / Trend Report, a market research publication that has covered the disk drive industry since 1975. It contains information on the dates of entry and exit for every firm worldwide that announced its intention to introduce a disk drive model, whether it actually produced one or not. It provides the technological and performance specifications of each disk drive model that was ever announced by each of these companies, together with the date on which the model was first shipped, if it was in fact put into production. The data set also measures the revenues and unit sales of each manufacturer, by market segment. It is a remarkably complete data set for the industry—not a sample of firms and products, but a complete census. A comprehensive search of the trade publications covering the industry, as well as personal interviews with over 90 industry executives, yielded information on only one company that had not been included in the Disk / Trend database—a company that incorporated but never was able to design and announce a product (Christensen 1993). Although Disk / Trend publishes data on the markets for floppy and rigid or hard disk drives, only the rigid disk drive industry was considered in the present study.

6. Method
We have used logistic regression on the likelihood that a firm will exit the industry in any given year. The general model used in this paper can be written:

$$\log_e(h_j / 1 - h_j) = [\beta_1 D_1 + \beta_2 D_2 + \cdots + \beta_D D_D] + [\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p],$$

where

- $h_j$ is the hazard at time $j$,
- $D_1$ to $D_D$ are dummy variables to denote the period that the record references (there are as many dummies as there are time periods in our data set),
- $X_1$ to $X_p$ are covariates or predictors, which can vary over time,
- $\beta$ and $\beta$ are parameters to be estimated, or alternatively,

$$h_j = 1 / (1 + e^{-[\beta_1 D_1 + \beta_2 D_2 + \cdots + \beta_D D_D] + [\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p]}),$$

which can then be fitted using standard logistic regression procedures (see Willett and Singer 1993 for details). Table 2 contains a summary of the variables we included or tested in our models and reports the significance of each variable when added to a model with only time dummies. This procedure helped us build our first model; subsequent chi-square tests allowed us to come to our best-fitted model, where all variables left were significant at the 0.05 level or better (plus one borderline case). This model is displayed in Table 3 and is discussed below.

7. Implications of the Significance Tests
The result of the careful approach to testing the significance of each parameter, contained in Table 2, allows us to make several interesting observations about the usefulness of each stream of literature in explaining the survival of firms in the disk drive industry.

Given the substantially different processes that lead to dissolution and divestiture, it would theoretically be desirable to analyze the two types of exits separately. One divestiture occurred in the sample prior to 1989, the sale of Vertex to Priam—though several more have occurred more recently but do not affect our data set. Since virtually all the exits in the sample have been dissolutions, that should be the interpretation of the term "exit" for the purposes of this analysis.
### Table 2  Variables Tested and Level of Significance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Rationale</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEAVE</td>
<td>Takes a value of 1 the year a firm exits the industry, 0 otherwise</td>
<td>The dependent variable</td>
<td>Not significant (0.12)</td>
</tr>
<tr>
<td>DENSITY</td>
<td>Number of firms active in the industry each year</td>
<td>Population ecologists argue that it is directly correlated with failure (e.g., Carroll and Hannan 1989)</td>
<td>Not significant (0.084)</td>
</tr>
<tr>
<td>DENSITSQ</td>
<td>Square of DENSITY</td>
<td>Same as above</td>
<td>Not significant (0.92)</td>
</tr>
<tr>
<td>WINCHESTER</td>
<td>A dummy variable with value =1 if firm was using the Winchester drive architecture in any year</td>
<td>One of the four components of the dominant design</td>
<td>0.001</td>
</tr>
<tr>
<td>ACTUATOR</td>
<td>A dummy variable with value =1 if firm was using the rotary voice coil actuator motor in any year</td>
<td>One of the four components of the dominant design</td>
<td>Not significant (25.24)</td>
</tr>
<tr>
<td>PANCAKE</td>
<td>Dummy =1 if firm was using the pancake motor in any given year</td>
<td>One of the four components of the dominant design</td>
<td>0.02</td>
</tr>
<tr>
<td>INTERFACE</td>
<td>Dummy =1 if firm was using embedded intelligent interface electronics in any given year</td>
<td>One of the four components of the dominant design</td>
<td>0.001</td>
</tr>
<tr>
<td>VARIETY</td>
<td>Total number of different models (8, 51/4, 31/2 inches, etc.) produced by each firm per year</td>
<td>Higher variety or mix flexibility makes a firm more competitive (e.g., Suárez et al. 1994)</td>
<td>0.05</td>
</tr>
<tr>
<td>ARCHINNO</td>
<td>A dummy variable with value =1 if the firm was an architectural innovator, as defined by Henderson and Clark (1990)</td>
<td>Christensen’s work (1993) suggests that architectural innovators tend to be more successful in this industry</td>
<td>0.001(25.88)</td>
</tr>
<tr>
<td>NEWMARKET</td>
<td>Dummy =1 if the firm entered in a new market as opposed to an established one</td>
<td>Christensen’s work suggests that entrants to new markets tend to be more successful.</td>
<td>0.001(36.67)</td>
</tr>
<tr>
<td>ARCHMARKET</td>
<td>Dummy =1 if an architectural innovator entered a new market</td>
<td>Interaction between the two previous variables.</td>
<td>0.001</td>
</tr>
<tr>
<td>INDSALES</td>
<td>Sales of the industry per year, in millions of dollars</td>
<td>Ecologists think that a larger market can “feed” more firms</td>
<td>Not significant (0.50)</td>
</tr>
<tr>
<td>FIRMSALES</td>
<td>Sales of a firm per year, in millions of dollars</td>
<td>Economists suggest the existence of economies of scale—larger firms have lower costs</td>
<td>0.001</td>
</tr>
<tr>
<td>SALEGROWTH</td>
<td>Industry sales growth (%) per year</td>
<td>Economists suggest that high-growth industries make it easier for a firm to stay in business</td>
<td>Not significant (58.22)</td>
</tr>
<tr>
<td>LNRRANK</td>
<td>Natural logarithm of entry timing. Entry timing starts at 1 for the first entrant, and so on.</td>
<td>First mover advantages concept in the management literature: early entrants have an advantage</td>
<td>0.001(17.96)</td>
</tr>
<tr>
<td>WINDOW</td>
<td>A dummy variable with value =1 if a firm entered the industry during the 1980–1983 time period, inclusive</td>
<td>There may exist a window of opportunity to enter, just before the dominant design gets established</td>
<td>0.01(9.44)</td>
</tr>
</tbody>
</table>

**Conventional Economic Variables.** Conventional economic arguments find limited support in our data. Only FIRMSALE, the variable measuring the effect of firm size on survival, was significant. The industry sales growth variable does not even pass the first significance test, which means that there is no relationship between the probability of failure of a firm and the industry rate of growth. We also tried other economic variables (not reported in the table), such as industry concentration measures, and they turned out not to be significant.

**Population Ecology Variables.** Population ecology postulates find no support in our data. Three variables (DENSITY), (DENSITSQ), and (INDSALES) fail to pass the significance test. That is, the probability of exiting the disk drive industry does not depend on the number of active firms in the industry, nor on the size of the industry in any given year.
Table 3  Best Fitted Model

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>St. Error</th>
<th>Significance</th>
<th>Delta $\chi^2$ *</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1_76</td>
<td>2.33</td>
<td>0.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2_77</td>
<td>2.36</td>
<td>0.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D3_78</td>
<td>2.52</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D4_79</td>
<td>2.27</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D5_80</td>
<td>2.03</td>
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* When dropped one at a time from full model; $n = 453.$

Technology Variables. Two of the five variables included in the final model can be considered technology strategy variables. WINCHESTER (Winchester architecture) and INTERFACE (intelligent interface) are the key architectural elements of the dominant product design. The two elements of the dominant design that were component technologies—PANCAKE and ACTUATOR—proved not to have statistically significant explanatory power in the survival equation. These results suggest that the dominant design is defined by the architecture of the product, rather than the individual components used as modules within it. This is consistent with the findings of Henderson and Clark (1990), Christensen (1992), and Iansiti (1995), which established that firms have a strong track record in continually improving component technologies—even radically new ones—within the framework of a dominant product architecture. Taken together, these findings suggest a modification to the dominant design framework proposed originally by Utterback and Abernathy (1975). Whereas they saw a shift in the focus of technology development from product design to process improvement after a dominant design emerged, these findings suggest that once a dominant architecture is in place, considerable technology development can continue at the component level as well as in manufacturing processes.

Strategic Variables. The other two variables that proved to have significant explanatory power are related to strategies the firms pursued. ARCHMARKET, the variable describing how the entrants targeted their initial product toward the market, emerged as a highly significant factor. Those entrants whose entry product was architecturally innovative, and who deployed that product in an emerging rather than an established market segment, enjoyed a much higher probability of survival. This supports the frameworks presented in Christensen and Rosenbloom (1995) and Christensen and Bower (1996) that a firm’s choice of which customers to serve has a powerful impact on the capabilities it develops and the strategies it can pursue.

Of the variables measuring entry timing, LNRANK—which was a rank-ordering of the sequence of firms’ entry into the overall industry—failed the significance test when added to the final model. In fact, LNRANK had a negative sign, indicating that later entrants would have a lower probability of failure. Our alternative hypothesis, that entry too early might be disadvantageous in situations where capabilities and knowledge rapidly become obsolete, was supported in the significance of the WINDOW variable.

VARIETY, which measures a firm’s ability to produce multiple product models at one time, is another variable that has attracted some attention in the management and population ecology literatures. It also failed the significance test.

8. Interpreting the Results of the Best Fitted Model

The best fitted model is shown in Table 3. Only five variables passed all the decrement to chi-square tests:4

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4 Our final model does not include a main effect of ARCHMARKET because both main effects are extremely correlated with the interaction variable, rendering estimators unreliable if included. Several tests were performed that supported our decision to include only ARCHMARKET in our model. Moreover, theory says that architectural innovators entering new markets will tend to be more successful. Thus, ARCHMARKET is consistent with the theory.
WINCHESTER, one of the dominant design variables, which takes a value of 1 if a firm used the Winchester architecture in its models, at any given year (0 otherwise).

INTERFACE, another dominant design variable, which takes a value of 1 if a firm used embedded intelligent interface electronics at any given year (0 otherwise).

WINDOW, the window of opportunity for entry variable, takes a value of 1 if a firm entered during the 1980–1983 period (0 otherwise).

ARCHMARKET, the entry strategy variable, takes a value of 1 if a firm entered a new market with an architectural innovation (0 otherwise).

FIRMSALES, the firm size or economies-of-scale variable, measures the sales of a firm per year in millions of dollars. The average annual firm sales for the sample is $64 million.

In order to interpret the results, consider first the sign of the five significant predictors of survival. The negative sign for each of them indicates that all are negatively correlated with the probability of failure. That is:

- The probability of failure is reduced if a firm was using each of the two significant elements of the dominant design: Winchester architecture and embedded intelligent electronic interface. Firms that did not adopt these two design features—i.e., did not adopt the dominant design—had a higher probability of failure.

- The probability of failure is reduced if a firm entered the industry during the period 1980–1983 (inclusive). This supports our hypothesis that in fast-changing industries such as this, there might be a short “window of opportunity” to enter the market. We believe this window to exist during the few years prior to the crystallizing of the dominant design.

- The probability of failure is reduced for firms that enter the industry targeting a new market segment—different from the established market dominated by the existing firms—with an architectural innovation. Note from Table 2 that it is the combined effect of the ARCHINNO and NEWMARKET variables (i.e., ARCHMARKET), which has the strongest effect (largest decrease in chi-square).

- The probability of failure is reduced for larger firms, when large is measured in terms of sales. For the calculations of the hazard profiles below, a “baseline” (small) firm was considered to sell $30 million/year, whereas a large firm has sales of $150 million/year.

We calculated the hazard function for five different scenarios. The baseline scenario (i) depicts a firm that did not use either of the dominant design concepts, did not enter the industry during the window 1980–1983, did not focus on a new market with an architectural innovation, and had a small size (sales of $30 million/year). Then, in scenarios (ii) to (v), we change the value of one covariate at a time, in order to see the effect of that covariate in the hazard profile. Substituting these numbers into Equation (2), and solving for \( h(t) \)—the hazard at year \( t \) results in a series of hazard profiles as illustrated in Figure 2.

Figure 2 is quite eloquent. First, consider only the baseline curve in Figure 2: its shape and level are a striking indication of the consequences of following a wrong strategy. Given the way we have defined the baseline scenario, our baseline firm depicts a firm with a weak position: it does not adopt the dominant design, does not enter the industry in the precise time window, and when it enters, it does so targeting the established markets—where the incumbent firms are strong—without the advantage of an architectural innovation. As the firm is necessarily small when it enters, it does not have the advantage of large size, nor due to its strategic choices is it able to grow to a critical size. A firm with such a strategy is very likely to fail soon, as we see by looking at the baseline curve. Such a firm has almost 0.9 probability of failure during the first year in the market, and that propensity to fail continues every year for almost all the data period, making it extremely hard for a firm with the wrong strategy to survive.

Figure 2 clearly shows the effect of a larger size on survival. Our baseline firm is five times smaller than our “large” firm. This latter firm, with sales of $150 million/year, has a hazard profile significantly more benign than the baseline firm: while the baseline firm had a probability of failure of more than 0.85 during its seventh year, the same probability was about 0.42 for a large firm. Note that size reduces the probability of failure, other things being equal, which does necessarily mean that larger firms will always survive. Indeed, several of the largest and most integrated firms dropped out of this industry in its earliest phase.
From Figure 2 it is also easy to see that firms that adopted the dominant design—i.e., firms that used both Winchester drive architectures and embedded intelligent electronic interfaces—had a clearly lower hazard profile than those firms of the baseline model. Indeed, the positive shift in the hazard profile is larger for these covariates than for any other variable in the model except for firm size, which suggests that in fast-paced industries such as the hard disk drive, adopting the dominant design features is crucial for survival.

The next most important influence on firm survival can be seen from Figure 2 to be entry during the 1980–1983 window. Firms entering during this period present a much lower probability of failure than firms entering earlier or later. For instance, while a firm entering during the 1980–1983 window had a probability of 0.50 of leaving the industry during its fifth year of business (see figure), the same probability for a firm that entered in a different period was 0.82.

Finally, Figure 2 shows how choosing an appropriate combination of innovation and entry market can significantly reduce a firm’s probability of failure. Architectural innovators entering new markets present a much lower hazard than baseline firms. For example, note from the figure that the probability of failure for a baseline firm during its sixth year of business is 0.80, whereas it is only 0.67 for a firm that is an architectural innovator and has entered into a new market. However, this is the least important of the significant variables in its effect in reducing hazard.

9. Implications for Management and Directions for Further Research

Even though our findings derive from an ex post view of the impact of dominant designs and windows of opportunity on the probabilities of survival, they offer some useful guidelines for managers who may find themselves in fast-paced, turbulent environments where, ex ante, it is not yet clear what the dominant design might be, and whether they might have entered their industry when its prime window of opportunity has opened, or whether they may have been early or late. This research implies four guidelines for decision-making that might prove useful for managers whose concern is to maximize the probability that their firms will survive in such situations.

First, there appears to be a significantly higher posterior probability of success for those firms that, at entry, chose architectural innovation as a technology strategy, and targeted new or emerging market segments as a commercial strategy—compared to firms whose strategy was to enter with component-level technological innovation targeted at established markets. When defin-
ing their firm’s entry strategy, managers should account for these odds.

However, this recommendation holds true only if a firm is entering prior to the definition of the dominant design and when a new market segment is emerging. If a firm decides it needs to enter a market after that market has become established, its managers should define their technology strategy by carefully assessing whether a dominant architectural design has yet emerged. If it has, the firm’s technology strategy at entry ought not to offer innovative architectural concepts in its initial products. While other studies have suggested that firms that enter after the emergence of dominant designs face a higher probability of failure than earlier entrants, our findings show that conforming to the dominant architectural design increases the probability of survival, regardless of whether a firm has entered its industry before or after that design has coalesced.

Second, for managers who have entered an industry prior to the definition of its dominant product design, our findings suggest that of all the technological innovations occurring in their environment, managers should specifically monitor any convergence toward architectural standardization—a tendency toward regularity across leading competitors’ new products in the way components relate to, or interface with each other. As dominant architectural characteristics emerge, managers should ensure that subsequent efforts to improve and differentiate products are focused around component-level innovation, and incorporate emerging architectural standards as rapidly as they can be discerned.

The third implication is for firms that find, ex post, that they have entered their industry too early, before the ideal window of opportunity opened immediately preceding the coalescence of the dominant design. Our findings suggest that the probability of such organizations surviving is troublingly low. We hypothesize that the reason might be that the capabilities that such firms develop in the early, fluid, nonstandard, low-volume phase of their industries’ histories, may render them uncompetitive in a post-dominant-design environment characterized by faster design cycle times, steeper ramps to volume production, and manufacturing standard products at low cost. Also, entering too early in fast-paced industries increases the chances that the acquired knowledge about markets and technology becomes obsolete and does not help the firm navigate through the key period that leads to the emergence of the dominant design.

Our research also helps to clarify certain issues in prior research and points to a number of potentially fruitful avenues for further research. For example, the fact that we considered several elements of technology strategy in our model permits us to build upon previous studies that have examined each of these elements separately. For instance, Christensen’s earlier work has stressed that the leaders of one generation of disk drives tended not to remain as leaders for the next generation. The interrelationship between this idea and that of a dominant design in the industry implies that Christensen’s findings are most applicable for the period before the dominant design. In a post-dominant design period it may be possible for a few dominant firms to stay as leaders for several generations. This hypothesis finds support in the disk drive industry after the late 1980s.

Our results also point toward certain improvements or modifications needed in other existing frameworks. In particular, the analysis suggests that “first-mover advantages” and most of the postulates of the entry timing literature might not hold true in fast-changing industries. Entry timing still has something to tell us about the success or failure of firms in these industries, but in a different way. We suggest the idea of a “window of learning” could be a more accurate way of conceptualizing the importance of entry timing in fast-paced industries—rather than simple first-mover advantages or even the alternative and more recent propositions reviewed above. We think the idea of a “window” of learning and opportunity—linked to the emergence of the dominant design—not only is supported by our data, but also has intuitive appeal and calls for further research and testing.

We also provide a clearer definition of the idea of a dominant design or standard, which may guide future research in this field. By tracing the main technical elements of a dominant design and their evolution over time, we have been able to determine more rigorously what it is and how it emerges—thus departing from noisier measures, such as the use of model sales or other nontechnology constructs. Moreover, according to our propositions here, the dynamics of how a dominant
design emerges should directly affect the size, temporal location, and duration of the window of opportunity to enter an industry. Further research is needed to shed more light on this important relationship.5

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References


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