

ECOLOGICAL DYNAMICS of *DE NOVO* AND
DE ALIO PRODUCTS IN THE WORLDWIDE
OPTICAL DISK DRIVE INDUSTRY, 1983-1999

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in the Worldwide Optical Disk Drive Industry, 1983-1999***

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Abstract

In this paper we developed a concept suggesting that initial entry conditions experienced by start-ups and diversified firms affect the behavior and fates of their products. Specifically, we predicted that in capital intensive industries, initial entry conditions confer advantages to diversifiers from related industries. As a result, these firms are likely to ship more models of products than start-ups. Products made by diversifiers are likely to have a longer market life span and exert a stronger competitive pressure than those made by start-ups. We tested these predictions on all products ever shipped in the worldwide optical disk drive industry, 1983-1999. The statistical analysis largely supported our theoretical predictions.

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Introduction

The actions of diversified businesses and start-up firms shape the face of many organizational populations. Given the importance of these two types of entrants for defining the competitive landscape of industries, it is essential to understand if there are differences in the behavior of start-ups and diversifiers, why these differences exist and what their implications are. The existing research in organizational theory has explored how and why diversifiers and start-ups differ in their entry conditions (e.g., Bruderl & Schussler, 1990; Klepper & Simons, 2000), innovation behavior (e.g., Anderson & Tushman, 1990, Henderson & Clark, 1990), and fates (e.g., Mitchell, 1994; Carroll, et al., 1996). It is assumed that differences in entry conditions of start-ups and diversifiers, such as resource endowment and prior experience, create differences in innovation behavior and result in different organizational performance and survival chances (e.g., Tushman & Anderson, 1986; Carroll, et al., 1996; Tripsas, 1997).

While the links between entry conditions, innovation behavior, and organizational fates have been explored both theoretically and empirically, very few efforts were devoted to understanding mechanisms by which entry conditions translate into innovation behavior and organizational outcomes. In this paper we propose one possible mechanism through which entry conditions may affect organizational outcomes. We suggest that product dynamics – the number of shipped products, market longevity of products, and competitive pressure generated by products – is one such mechanism. In particular, we assume that differences in entry conditions between start-ups and diversifiers might lead to differences in their product dynamics. The likely result of this process is different organizational outcomes. As the first step toward understanding the mechanism of product dynamics, we look at how start-ups and diversifiers differ in their product behavior.

No research has explored the difference in product dynamics made by the two types of entrants. This study addresses this gap by proposing a concept about product behavior made by start-ups and diversifiers and testing this concept on a comprehensive dataset on the worldwide optical disk drive industry, 1983-1999. We argue that a firm's entry conditions, such as prior experience and resource endowment, significantly shape the firm's propensity to engage in certain types of innovation. This influence leads to specific product outcomes, such as the number of products made by the firm, market longevity of its products, and product competitiveness that affect organizational outcomes like performance and survival. We also suggest that in capital intensive industries, entry conditions confer advantage to diversifiers from related industries that leads to a situation when diversified businesses offer a greater number of products, which have longer market life spans and exert stronger competitive pressures.

The paper proceeds as follows. First, we review existing organizational research that compares behavior and fates of diversifiers and start-ups. This review covers innovation literature and literature on performance and survival chances of the two types of entrants. We also describe contributions and unsolved problems of this research. Second, we focus on product dynamics of the two types of entrants. We review existing empirical literature on products and show that no research has been done to understand the differences in product dynamics of diversifiers and start-ups. Third, we describe the empirical setting of the optical disk drive industry, on which we test our concept. Fourth, we outline our concept explaining the differences in product behavior between the two types of entrants. We develop a set of testable hypotheses based on this concept and describe the methodology used to test these hypotheses. Next, we describe the results and finally, we discuss the findings.

BACKGROUND

Comparative research on diversifiers and new start-ups in existing organizational literature is centered on two major issues. One stream of literature focuses on how entrant status of a firm affects its survival chances (Carroll et al., 1996; Mitchell, 1994; Klepper & Simons, 2000). The other stream of literature seeks to understand how and why established firms and start-ups differ in innovation behavior (Anderson & Tushman, 1990; Christensen & Rosenbloom, 1995; Henderson & Clark, 1990). In this section, we review both streams of research and describe their unsolved problems. Following Carroll et al. (1996), we refer to new start-up entrants as *de novo* entrants or producers. We refer to diversifiers as *de alio* producers. The two terms come from Latin and literally mean ‘from anew’ and ‘from another’ accordingly.

Research on firms’ innovative behavior suggests that differences in entry conditions, such as resource endowment and previous experience, can result in the propensity of *de alio* and *de novo* firms to engage in different types of innovation. There is tentative agreement in this literature that *de alio* entrants are likely to be a major source of incremental innovation that is built on existing know-how and introduces relatively minor changes to an existing product or process. *De novo* entrants are assumed to be responsible for the introduction and development of most radical innovations that are built on knowledge that does not relate to an existing one and that demands a completely different set of principles (Anderson & Tushman, 1990; Tushman & Anderson, 1986; Henderson, 1993).

Radical change by diversified firms is difficult and error-prone for various reasons. New organizational routines have to be developed quickly. Yet their path dependent nature makes the change difficult and slow (Nelson & Winter, 1982). Commitment to old technologies may block implementation of new production principles (Henderson & Clark, 1990). Attachment to

outdated practices resulting from competency traps and myopia of learning makes it difficult for *de alio* firms to handle innovations demanding completely different approaches (Levitt & March, 1988; March, 1991; Levinthal & March, 1993). Complementary assets developed in the industries of previous activity can be difficult or even impossible to redeploy (Teece, 1986; 2000; Tripsas, 1997). Finally, internal political resistance created by changes in a firm's reward and status systems may bring the innovation process to a halt (Pfeffer & Salancik, 1978; Pfeffer, 1981). In contrast to *de alio* firms, researchers agree that *de novo* organizations do not usually face these constraints and are consequently more successful at both seeing the opportunity and developing radical innovation. On the other hand, it is widely stated that the inertial processes that make *de alio* producers worse at radical innovation help them succeed better than start-ups at incremental innovation (Hannan & Freeman, 1984; Anderson & Tushman, 1990; Teece, 2000).

The consensus that *de alio* firms are more successful at incremental innovation, while *de novo* firms are likely to succeed at radical innovation might, however, be more an illusion than a reality. The empirical tests supporting the previous statement are far from rigorous. Selection bias is a serious issue in these studies. The distinction between radical and incremental innovation is always made retrospectively by the subjective judgment of experts (e.g., Anderson & Tushman, 1990; Henderson, 1993; Tushman & Anderson, 1986). Specifically, there is always a question whether an innovation under observation is labeled radical because of its inherent characteristics or because of the fact that the established firms failed to undertake it. Ad hoc explanations for cases that do not fit the theory are not rare. Other empirical studies, which use more objective measures, such as R&D spending and products, fail to show uniformly that innovative input and output are non-proportionally related to firm's size. Including firm and

industry controls into statistical models makes these tests inconclusive (Cohen, 1995; Freeman & Soete, 1999: 227-242). Yet another challenge comes from an emergent body of empirical research that demonstrates that some *de alio* firms have been successful at introducing and developing major innovations (e.g., Christensen & Bower, 1996; Methe, et al., 1996).

The unresolved difficulty in the innovation literature of distinguishing *ex ante* between radical and incremental innovations and demonstrating that start-ups and diversifiers are better mostly at a certain type of innovation, makes the innovation approach problematic and limited for comprehending differences between *de alio* and *de novo* firms. The research that focuses on a comparison of behavior and fates of *de novo* and *de alio* organizations looks more promising for understanding differences between the two types of entrants and the consequences of these differences for firm-level and industry-level outcomes.

Research on the fates of different types of entrants explores why and how diversifiers and start-ups differ in their survival chances and types of ending events. The general idea underlying this research is that the initial resource endowment and previous experience help *de alio* firms have lower mortality rates than *de novo* firms that lack both resources and capabilities. Over time, however, more flexible *de novo* firms can experience lower mortality rates if the environment changes faster than the inertial *de alio* producers do (Carroll, et al., 1996). This theoretical speculation was supported by empirical studies that demonstrated that *de alio* entrants have, on average, lower mortality rates than *de novo* producers. For example, Carroll, et al. (1996) found that in the U.S. automobile industry, *de novo* producers had higher initial mortality rates than *de alio* firms. *De alio* producers started with lower mortality rates, but with age these rates converged with those of *de novo* firms. In another study, Mitchell (1994) demonstrated that, in the U.S. medical sector, the dissolution rate declined with greater sales and age for *de*

novo firms. The dissolution rate for *de alio* firms declined with greater sales but was unaffected by business age. Both *de novo* and *de alio* firms became more likely to sell their businesses over time. Also, when age and sales were controlled for, *de alio* entrants were more likely to sell their businesses than start-ups. In the study of the U.S. television receiver industry, Klepper & Simons (2000) found that *de alio* entrants from radio industry had greater market share, higher innovation rates, and longer survival than either *de novo* firms or diversifiers from other than radio industries.

Comparative research on *de novo* and *de alio* firms persuasively demonstrates the existence of essential differences in the behavior and fates of the two types of entrants. Given that, it is important to understand why these differences occur. The literature suggests that resource endowment and previous experience are the two key sources for the observed differences (Bruderl & Schussler, 1990; Carroll, et al., 1996; Klepper & Simons, 2000). This literature, however, leaves one important issue unresolved: The mediating mechanisms between the initial conditions of resource endowment and prior experience, on the one hand, and resulting behavior and fates of *de novo* and *de alio* firms, on the other, are not well understood. While there is theoretical speculation about such mechanisms, there is little empirical investigation of them. In this study, we propose to empirically examine one possible mediating mechanism between initial conditions and resulting fates of the two types of entrants. We suggest that differences in entry conditions of *de novo* and *de alio* firms lead to different dynamics of products made by the two types of producers. Product strategy has been found to have direct implications for organizational performance and survival (Barnett & Freeman, 2001; Barnett & McKendrick, 2001; Dowell & Swaminathan, 2000; Greenstein & Wade, 1998; Sorenson, 2000). Thus, understanding the differences in product dynamics of start-ups and diversifiers can be one

of ways to explicate the mechanisms driving the differences between fates of *de novo* and *de alio* producers.

Although no research has examined how the behavior and fates of products made by *de novo* and *de alio* firms differ, some empirical research has been conducted on general product behavior. For instance, it was found that, in the U.S. semiconductor industry and in the early U.S. bicycle industry, while the greater number of products enhanced organizational survival, simultaneous introduction of multiple products temporarily increased firms' failure rates (Barnett & Freeman, 2001; Dowell & Swaminathan, 2000). The suggested reason for such an outcome is that multiple product introductions create a severe interruption in a firm's operational routines. In the U.S. bicycle industry, mainframe computer systems market, and in the computer workstation manufacturers market, it was demonstrated that number of products increased organizational survival chances in turbulent and uncertain environments (Dowell & Swaminathan, 2000; Greenstein & Wade, 1998; Sorenson, 2000). The proposed explanation for this finding is that multiple products allow firms to diversify the risk and to detect shifts in customers' preferences. In the early U.S. bicycle industry, temporal overlap in production between and within the sequential generation of products affected organizational mortality in a non-monotonic way. While, overlap initially lowered mortality rates, after a few years, it increased them. These effects were stronger for between-generation overlap when compared to within-generation overlap. It was suggested that temporary overlap at the earlier stages of new product development is beneficial because it creates a smooth transition from old production routines to new ones. Overlap that continues for a prolonged period becomes detrimental, because the old production process still requires resources but results in an obsolete, unpopular product (Dowell & Swaminathan, 2000).

Given that product dynamics plays such an important role in organizational fates, it is important to understand what factors contribute to the length of a product's market life span. There are few empirical studies that looked directly at the determinants of product introduction and exit. For example, Greenstein & Wade (1998) found that, in the commercial mainframe computer market, products are more likely to disappear as they get older. Increasing cannibalization, density of substitute products, and density of all products in size class increase product exit rates. Product entry and exit differs across market niches. Products face competition not only from products in their own size class but also from products in surrounding size classes. In another study, de Figueiredo & Kyle (2001) explored reasons for product exit in the desktop laser printer industry. They found that product density is a major factor driving products out of market. Economies of scale and learning have only marginal effect on product exit.

While these studies provide important contributions to our knowledge about product behavior, no research has addressed potential differences in product dynamics for *de alio* and *de novo* firms. Understanding differences in the behavior of *de novo* and *de alio* products may be one way to explicate a mediating mechanism between entry conditions and organizational fates of the two types of firms. Discovered differences in the fates and innovation patterns of *de novo* and *de alio* firms point to the existence of important differences in the ecological dynamics of products made by these firms. The purpose of this paper is to propose a concept that predicts and explains these differences, and to test it empirically using a comprehensive dataset on all optical disk drive products ever shipped in the world from 1983 through 1999.

Background on Optical Disk Drives

Technology. The key product of the optical disk drive industry is an optical disk drive, which is one of the devices (among hard drives, floppies, tapes, disk arrays, etc.) used for storage and retrieval of information. The optical method for data storage is based on the recording and retrieval of information with the help of a laser. Optical disk systems are composed of two main components: a disk for storage and a drive for recording, retrieval, and output (Purcell, 2000).

An optical disk consists of four layers: a polycarbonate substrate layer, a reflective layer, a protective layer, and the label. Optical storage media use the intensity of reflected laser light as an information source. In the polycarbonate substrate layer, a laser beam encounters holes that correspond to the coded data, which are called *pits*. The areas between these pits are called *lands*. The substrate layer is covered with a thin reflective layer. The laser beam is focused on the reflective layer from the substrate layer. The reflected beam has a strong intensity at the lands and a weak intensity at the pits.

The process of optical recording and the retrieval of information can be described as follows. Information is stored on a polycarbonate disk in the form of pits. During recording pits are generated by a laser beam. The stored digital information can later be retrieved by an optical disk drive. The drive's optical pickup creates a laser beam directed at the spinning disk. Logic timing circuits can register the difference between distance the light travels when it strikes lands and distance the light travels when it strikes pits. The pattern composed of pits and lands corresponds to the coding of 1s and 0s. The reflected signals are directed to a processor that reads the reflection and converts it into a stream of digital pulses, which in turn are converted into text, pictures, or sounds. The entire system is controlled via a microprocessor-based central processing unit.

Brief History of the Optical Data Storage Technology. In 1972, Philips Corporation announced a method of optical storage of audio content based on analog modulation techniques. The analog modulation approach was soon abandoned in favor of more promising digital signal encoding methods. During the same period, Sony Corporation was engaged in research to perfect error-correction methods that could be applied to digitally encoded audio. Collaboration between Sony and Philips resulted in the merging of Philips's signal format with Sony's error-correction method, and in June of 1980, the two companies introduced their proposal for the Compact Disc Digital Audio system. The proposed standard was adopted by 25 manufacturers and efforts shifted toward retooling the industry to support manufacturing products incorporating the new standard.

Adoption of the optical method for audio storage was paralleled by efforts of Philips, Sony, NEC, and other companies to develop techniques for storing data on disk. The result of these efforts was the CD-ROM (Compact Disk – Read Only Memory) format, tagged Yellow Book, which was introduced in 1985. Initially the costs and dismal performance discouraged many potential users. However, further development drove costs down and improved performance. In 1986, a number of industry representatives agreed on a common file system structure that became known as the High Sierra format. Following increasing adoption rates of High Sierra format, this format was formalized as ISO 9660 standard in 1988. ISO 9660 standard had a noticeable stimulating effect on the development of CD-ROM technology (Disk/Trend Report, 1998; Purcell, 2000)

The success of the audio CD and eventual acceptance of CD-ROM stimulated manufacturers to introduce and promote numerous types of digital storage products, some of which failed on the market but some of which still exist in various forms (please, see Figure 1).

The next-generation device, introduced in the mid-1980s, provided a flexible write-once, read-many (WORM) capability. This enabled end-users to record and playback computer data from the same drive. The third generation optical disks, today's rewritable systems, were introduced in 1988. They offer record, playback, and erase capabilities.

Two different digital videodisk formats emerged in January 1995. One camp, led by Toshiba, introduced the Super Density format. Sony and Philips devised their own approach – the Multi Media Compact Disc. In December 1995, the charter for the DVD Consortium was drawn up and dissension among the industry leaders diminished as the standard for the Digital Versatile Disk (DVD) was formalized. The first DVD players were shipped in 1996.

The industry has been always characterized by format wars. The firms that instigated format wars were mostly large *de alio* producers fighting to increase their market share. The Optical Storage Technology Association (OSTA) was established in 1992 with a goal to end format wars by promoting industry standards that would allow compatibility across different types of drives and manufacturers. In 1997 OSTA developed MultiRead specification that enables all classes of CD disks to be read on current and future CD and DVD devices. The efforts of OSTA to promote the common standard succeeded in 2000, when seventeen CD drive manufacturers, representing over 90 percent of all CD optical drive shipments worldwide, have achieved compliance with MultiRead specification.

[Figure 1 about here]

Demographics of the Industry. Two types of firms have been populating the optical disk drive industry. As Figure 2a shows, there have always been a large number of diversifiers and only a small number of start-ups. For the history of industry development, 83 diversifiers entered the industry and 47 failed, 24 start-ups entered the industry and 18 failed. 80 out of 83

diversifies came into the optical disk drive industry from related industries: computers and compute peripherals, consumer electronics, electronic and electrical components, and optics.

Given the extreme capital intensity of optical disk drive production and the severe format wars, the dominance of *de alio* firms in this industry is not surprising. However, given the high rate of innovation in this industry, the poor role played by *de novo* firms is surprising. The concept developed in this paper may help to understand the *de alio* dominance in the optical disk drive industry by explicating the ecological dynamics of *de novo* and *de alio* products and their role in organizational survival.

[Figures 2a and 2b about here]

THEORY AND HYPOTHESES DEVELOPMENT

Based on the literature on the fates of *de novo* and *de alio* firms and the literature on innovation we propose a concept that explicates a possible mechanism underlying the differences between organizational outcomes of the two types of entrants. Specifically, we suggest that a firm's entry conditions, such as prior experience and resource endowment, affect the firm's propensity to engage in incremental, radical, or architectural innovation. The firm's innovation behavior affects how many products it offers and the extent to which these products are attractive to customers. Arguably, the number of products, the length of their market life, and the competitive pressure they are able to exert significantly define the firm's performance and survival chances. Figure 3 explicates the described conceptual links.

[Figure 3 about here]

While there have been a number of studies that examined the link between entry conditions and innovation behavior (e.g., Anderson & Tushman, 1990; Henderson & Clark, 1990; Henderson, 1993; Klepper & Simons, 2000), between innovation behavior and

organizational outcomes (e.g., Cohen & Levinthal, 1990; Carroll & Teo, 1996; Barnett & McKendrick, 2001), and between product strategy and organizational outcomes (e.g., Barnett & Freeman, 2001; Dowell & Swaminathan, 2000; Greenstein & Wade, 1998; Sorenson, 2000), there is no research that examines how a firm's entry conditions and resulting propensity to engage in certain types of innovation behavior affect the firm's product dynamics or product-level outcomes. This paper focuses on this conceptual link. In particular, it addresses the issue as to how entry conditions and resulting innovation behavior affect firm-level and industry-level ecological dynamics of products: the number of products shipped by firms, the length of market life of these products, and the strength of competitive pressure these products exert.

To ensure the precision of conceptual predictions, we limit our theorizing by three boundary conditions. First, because the optical disk drive industry belongs to manufacturing, capital intensive industries, the concept developed here refers only to this class of industries. Second, since 96.4% of optical drives *de alio* firms (80 out of 83) are diversifiers from related industries, our concept speculates about product dynamics made by *de novo* firms and *de alio* firms from related industries. Finally, because the optical disk drive industry has been characterized by severe format wars, our concept refers to product dynamics in industries with multiple competing standards. Product dynamics described in this paper can be different from those in the industries with low capital intensity or industries with large number of 'unrelated' diversifiers or industries with few widely adopted standards.

Hypothesis Development

There are three groups of possible factors that can affect ecological dynamics of products. First, organizational characteristics may influence product behavior on the market. Second, the technical parameters of the product can shape its market life span and competitiveness. Third,

environmental forces can influence the product's fate. To create testable hypotheses, we consider these three groups of factors with a special focus on the factors that can help understand *de novo/de alio* differences.

Organizational Factors. To understand the ecological dynamics of products of *de novo* and *de alio* firms, the first question to be answered is what type of entrant offers more models of products. Literature on innovation suggests that sometimes start-ups can offer more models based on a new radical technology if the production process is not capital intensive (Freeman & Soete, 1999). However, in capital intensive industries, even in periods of great technological variation, the introduction of a product to the market requires significant resources. Since *de alio* firms have more resources (Bruderl & Schussler, 1990; Carroll, et al., 1996) and complementary assets (Teece, 2000; Tripsas, 1997) they should be expected to offer more models of products than *de novo* firms. These observations lead to the following hypothesis:

Hypothesis 1: *De alio* firms ship more models of products than *de novo* firms.

Empirical studies show that a firm's product strategy significantly affects its survival chances. In particular, it has been consistently demonstrated across three different studies that in turbulent environments, the more products the firm has on the market, the better its survival chances (Dowell & Swaminathan, 2000; Greenstein & Wade, 1998; Sorenson, 2000). At the same time, simultaneous introduction of multiple products increases a firm's hazard of exit (Barnett & Freeman, 2001; Dowell & Swaminathan, 2000). Together these findings suggest that a firm is likely to be better off when it has products with a longer market life. Given this tendency, it is important to understand what factors define the length of a product's stay on the market.

Two types of product stay on the market longer. First, products that are profitable, e.g., those that generate large sales volumes, stay on the market longer than unprofitable ones. Second, a manufacturer may keep some unprofitable products in production. Keeping the production of unprofitable products may have an indirect positive pay-off: In uncertain environments multiple differentiated products, both profitable and unprofitable, allow a manufacturer to detect shifts in customer preferences (Sorenson, 2000).

We propose that products made by *de alio* and *de novo* firms are likely to have different chances of staying on the market. In particular, we suggest that *de alio* products stay on the market longer than *de novo* products, both because *de alio* products are more likely to be market success and because *de alio* firms are more likely to have greater abilities of maintaining the manufacturing of unprofitable products.

There are several reasons why *de alio* products are likely to enjoy higher market success rates. First, customers may prefer *de alio* products when it is difficult to judge the product quality before purchase. There is inherent uncertainty regarding the quality of *de novo* products, because *de novo* firms do not often possess a reliable performance reputation (Stinchcombe, 1965; Aldrich & Fiol, 1994; Stuart, et al., 1999). As such, customers may prefer to buy products made by *de alio* firms with established reputations in the industries of prior related activity. Customers may be reluctant to risk buying products of unknown *de novo* producers that lack such a reputation (Rao, 1994). As a result, *de novo* products are less likely to be market success and more likely to have a shorter market life than *de alio* products.

Second, even if it is possible to evaluate the quality of *de novo* and *de alio* products before purchase, *de novo* products may be at a disadvantage. When *de novo* firms enter an industry they do not have established routines, so they must develop them. This development

requires time and resources (Stinchcombe, 1965; Hannan & Freeman, 1989). In contrast, *de alio* firms have established routines that were developed in industries of prior related activity. Well-developed routines are one of the key factors for manufacturing highly reliable products (Nelson & Winter, 1982; Hannan & Freeman, 1984). Thus, *de alio* firms are better able to develop higher quality products than *de novo* firms are. As a result, *de alio* products are likely to have higher success rates and stay longer on the market than *de novo* products.

Third, the differences in the quality of *de alio* and *de novo* products can be driven by differences in time, financial, and human resources, which the two types of producers possess. *De novo* firms face greater time constraints than *de alio* producers when they work on the development of new products. Specifically, *de novo* firms must focus on fast product introduction since it helps them to gain early cash-flow for greater financial independence, to gain external visibility and, therefore, legitimacy, to gain early market share, and to improve likelihood of survival (Schoonhoven, et al., 1990). Greater time pressures create incentives for *de novo* firms to develop new products as quickly as possible. A likely result of this time pressure is an introduction of immature, undeveloped, low quality products into the market. Financial constraints often experienced by start-ups may further contribute to the mediocre quality of their products (Aldrich & Fiol, 1994). *De novo* firms may also have trouble attracting qualified human capital, which can negatively influence the reliability of their products (Stinchcombe, 1965). In contrast, *de alio* firms have portfolios of previously developed products and slack resources (Carroll, et al., 1996; Sorenson, 2000). The described differences in resource constraints faced by the two types of entrants should result in higher disappearance rates of *de novo* products in comparison to *de alio* products (especially, when product imitation or substitution is feasible).

Fourth, *de alio* firms have complementary assets that *de novo* firms usually have not yet developed. Complementary assets are important for timely production, economy of scale, learning effects, and successful marketing. Complementary assets are very time and resource consuming to create (Teece, 1986; 2000). As a result of a lack of complementary assets, *de novo* firms first make products that are less attractive to customers on a price dimension, and second, are not able to promote their products on the market as effectively as *de alio* firms can. Consequentially, *de novo* products may have smaller market success rates.

Finally, *de novo* firms are more likely to introduce radical innovations into their products (Tushman & Anderson, 1986; Henderson & Clark, 1990; Henderson, 1993). Radically innovative products tend to experience quick turnover that results from severe competition from old and new technologies (Anderson & Tushman, 1990). Also, radical designs introduced by *de novo* firms almost never become dominant that contributes to a shorter market life of products based on this design (Anderson & Tushman, 1990; Tushman & Rosenkopf; 1992).

The second general cause for greater market longevity of *de alio* products is that *de alio* firms may maintain production of unprofitable products. Although such products are not market success, they still contribute to overall firm performance, because keeping multiple products in uncertain markets allows firms to detect shift in customers' preferences (Sorenson, 2000). *De alio* firms are more likely to pursue this product strategy, because they have more necessary slack resources than *de novo* firms (Penrose, 1958; Teece, 1982).

Thus, all the described reasons point out that *de novo* products are likely to have higher market disappearance rates than *de alio* products.

Hypothesis 2: *De novo* products have higher market disappearance rates than *de alio* products.

Technical Factors. Longevity of products on the market can be shaped to a significant extent by their performance characteristics. Specifically, the fates of the products depend on how close performance parameters of these products to those of technological frontier. The literature suggests that products with better performance characteristics in a given class have higher attractiveness to customers (Anderson & Tushman, 1990; Henderson & Clark, 1990; Greenstein & Wade, 1998; Sorenson, 2000). Thus, innovative products with performance parameters closer to those of the industry top technological frontier are more likely to enjoy greater success chances and, as a result, to stay on the market longer.

De Figueiredo & Kyle (2001) suggested the existence of the second, bottom frontier. They proposed that a bottom technological frontier is driven by the desire of manufacturers to reach the mass market. Firms may look to produce inexpensive products that are attractive to unsophisticated and price-sensitive customers. This involves both processes and product innovation and two tactics are likely. First, firms can eliminate certain product features found on higher end models. Second, they can change product design and manufacturing techniques. The existence of a bottom technological frontier was demonstrated in the laser printer industry (de Figueiredo & Kyle, 2001).

Another support for the existence of a bottom technological frontier comes from the literature that suggests that in many industries more advanced and less advanced technologies appeal to different customers and, therefore, compete on a different basis (Podolny & Stuart, 1995). Moreover, producers competing at technological edges (either top or bottom) face fewer competitors than firms competing in the middle of technological distribution do (Barnett & McKendrick, 2001). This finding suggests a longer market life of products made by firms at either top or bottom frontiers.

This discussion makes it possible to predict that the products with performance parameters closer to a top technological frontier as well as the products with performance parameters closer to a bottom technological frontier have higher market success chances and, therefore, lower market disappearance rates. A possibility of dual frontiers in many technology intensive industries suggests the following hypothesis:

Hypothesis 3.1: The closer a product's performance parameters to either the top or the bottom technological frontier, the lower its market disappearance rates.

De novo and *de alio* products are likely to differ with respect to dual frontiers. Both types of entrants can introduce competitive products at a top technological frontier. *De alio* firms have the necessary resources and complementary assets to be successful at incremental innovation (Anderson & Tushman, 1990; Tripsas, 1997), while *de novo* firms are flexible enough to introduce radical and architectural innovations (Anderson & Tushman, 1990; Henderson & Clark, 1990; Christensen & Rosenbloom, 1995). Regardless of the nature of innovation, by which the two types of entrants improve performance characteristics of their products, they can innovate their products to be strong competitors at a top frontier.

The story is different for a bottom technological frontier. The key reason why products at a bottom frontier can be competitive is that some customers prefer low price of a product to technical superiority (de Figueiredo & Kyle, 2001). Due to economies of scale, *de alio* firms can achieve much lower prices on low end products than *de novo* firms (Potter, 1985). Consequently, while *de alio* products can be expected to compete successfully at the both top and bottom frontiers, *de novo* products are likely to be success only at the top frontier. This prediction leads to the two hypotheses:

Hypothesis 3.2: Disappearance rates of *de alio* products have an inverted U-shape function with the distance from technological frontiers: they decrease as product performance parameters approach either a top frontier or a bottom frontier.

Hypothesis 3.3: Disappearance rates of *de novo* products have a positive relation with the distance from a top technological frontier: they decrease when product performance parameters approach a top frontier.

Although products closer to the bottom frontier may have higher survival chances than those in the middle of the performance distribution (i.e., between the two frontiers), they are likely to disappear from the market faster than products closer to the top frontier. One of the possible reasons for this occurrence is that the performance parameters of less advanced products can be improved much faster than those of more advanced products (Anderson & Tushman, 1990). As a result, market turnover of less advanced products is likely to be higher than that of more advanced products. This speculation suggests the following hypothesis:

Hypothesis 4.1: Technologically advanced products (i.e., those close to the top technological frontier) have lower disappearance rates than technologically non-advanced products (i.e., those close to the bottom technological frontier).

It is difficult to predict if there is a difference between survival chances of technologically advanced products made by *de novo* and *de alio* firms. Both types of the entrants are capable of introducing important innovations that can contribute to product survival chances. Since *de novo* and *de alio* firms are thought to be better at different types of innovation, we predict that there is a difference in the market longevity chances of their technologically advanced products. However, we cannot predict the direction of this difference and let the data show what the direction is.

Hypothesis 4.2: The survival chances of technologically advanced products differ for *de novo* and *de alio* products.

Environmental factors. Different exit rates of *de novo* and *de alio* products can shape the competitive intensity of these products. To examine this possibility, we look at the environmental factors related to the *de novo/de alio* distinction that can affect competitive processes. Specifically, we analyze the consequences of differences in disappearance rates between *de alio* and *de novo* products for the competitive dynamics of the industry product population.

The densities of *de novo* and *de alio* products can differentially impact product longevity. If it is true that *de alio* products are likely to have higher market longevity rates as predicted by Hypothesis 2, then it is possible to suggest that the density of *de alio* products generates a stronger competitive effect on all products than the density of *de novo* products. Another reason why *de alio* products can be strong competitors is that in capital intensive industries most innovations come not from *de novo* producers but from *de alio* firms (Freeman & Soete, 1999). This discussion generates the following hypothesis:

Hypothesis 5.1: Density of *de alio* products increases disappearance rates of all products more than density of *de novo* products.

Hypothesis 4.1 predicted that technologically advanced products have higher market longevity rates than technologically non-advanced products. If this is true, then it is possible to predict that advanced products have stronger competitive effect on all products than non-advanced products. This prediction can be formulated as the following hypothesis:

Hypothesis 5.2: Density of technologically advanced products increases the disappearance rates of all products more than density of technologically non-advanced products.

The competitive effects of technologically advanced and non-advanced products can differ by a firm's entry status. Combining the predictions that generated Hypotheses 5.1 and 5.2 suggests that *de alio* technologically advanced products are likely to generate the strongest competitive pressure. So, we propose the following:

Hypothesis 5.3: Density of *de alio* technologically advanced products increases the disappearance rates of all products more than either density of *de alio* non-advanced products or density of *de novo* advanced products or density of *de novo* non-advanced products.

METHODOLOGY

Population Studied/ Data Source

We test our hypotheses on the population of all optical disk drive producers that operated in the worldwide market from the beginning of the industry in 1983 through the end of 1999, the last year of full coverage from the most comprehensive data source available.

The data come from Disk/Trend, Inc., a market research company located in Mountain View, California. Disk/Trend publishes annual reports on different data storage devices, including optical disk drives. The first Disk/Trend report on optical disk drives was published in 1985. The reports publish technical specification on each product shipped by each producer of optical disk drives. There is also firm-level data on revenues and unit shipment for the largest firms in the industry.

Sometimes Disk/Trend reports list products that were announced but never made it to market. Therefore, products listed as preliminary specification and products for which the announced date of the first customer shipment is greater than or equal to the date of the last customer shipment, are not included in our analysis.

Starting events of production. We define a product introduction when it is first shipped to the customer market. The Disk/Trend report provides information on the first customer shipment of varying degrees of precision. Disk/Trend gives some dates with precision to the month, others with precision to the quarter, and still others with precision to the year. To make the analysis tractable, all the information about timing was converted to decimal years. Dates given to the month were coded as occurring at the beginning of the month. Following Petersen's recommendations for dealing with the problem of time aggregation (1991), dates given to only the quarter were coded as occurring at the midpoint of the quarter. Dates given to only the year were coded as occurring at the midpoint of the year.

Ending events of production. We define a product's exit/disappearance from the market when it stops being shipped to retailers from the manufacturers, although it may still be available in some retail outlets from inventory. The Disk/Trend report does not provide exact information on the last customer shipment of the product. The report comes out in the third quarter of each year. It covers revenues and unit shipment for the previous calendar year, but it covers firms and products for the current year. Based on this information we assumed that the last shipment of the product happens in the third quarter of the year the product is last mentioned in a Disk/Trend report and coded product exit as occurring at the midpoint of the third quarter of that year.

From 1983 to 1999, 107 firms entered the worldwide optical disk drive industry, and 65 failed. The data include 662 firm-year observations. These firms shipped 1,358 products on the worldwide optical disk drive market, of which 1,053 products exited the market. The data include 3,078 product-firm-year observations.

Operationalization of Variables

Dependent variable. The ‘dependent variable’ in this study is product exit (disappearance) rates. *Product exits* include termination of shipment. A product is considered as exited in year t if it is not shipped in year $t+1$.

Independent variables. There are several independent variables in this study. Unless otherwise noted, all are updated annually. The dummy variable *de novo* takes a value of one if a product is made by a start-up entrant, and a value of zero if it is made by a diversified entrant. This variable is meant to test Hypothesis 2 about a shorter market life span of *de novo* products as compared to *de alio* products. The variable is time-invariant.

The variable *data access time* is used to test Hypotheses 3.1-3.3 about effects of being at the top or bottom technological frontier on a product’s length of life. Data access time is the physical operation associated with positioning the read/write head of a storage device in the proper location to read or write a particular piece of data. For CD-ROM application, the seek operation generally requires varying the rotational speed of the disk in relation to the radial position of the laser read head. Technically, data access time is the sum of the average positioning time plus the rotational latency (the inherent delay experienced by the laser read head when locating specified data). Data access time is an appropriate technical parameter to test the hypothesis, because it is one of few important indicators of optical disk drive performance (Disk/Trend Report, 1999; Purcell, 2000). Technically, market attractiveness of an optical disk drive is defined not only by its time performance but also by its recording capacity. Historically, however, time performance parameters have turned out to be much more decisive than recording capacity in defining the attractiveness of optical disk drives to users and in shaping their chances

to compete with other types of drives, e.g., hard drives (Disk/Trend Report, 1999; Merrill Lynch & Co. and McKinsey & Company Report, 2001).

Data access time is measured in microseconds. Smaller access time signifies better performance of a drive. Figure 4 shows that as the industry evolved, average data access time has decreased. To make the effects of product data access time across different years easily interpretable, we standardized its measure by dividing a product's data access time in each year by the industry's mean data access time in the year. This standardized measure of data access time was used for all analyses in this paper.

[Figure 4 about here]

The higher the product's data access time, the further away this product's performance from the top technological frontier. As speculated earlier, products with performance at the bottom frontier can serve a niche of the market with users who are ready to sacrifice superior performance for a significant reduction in price. To test the hypothesis that a product with performance at either top or bottom technological frontiers has higher survival chances, both *linear* and *squared data access time* terms are entered into the model. Interactions between the data access time and the *de novo* and *de alio* status variables are used to examine the differences in the importance of being closer to either top or bottom technological frontier for *de novo* and *de alio* products.

We use the data access time variable to create a dummy that tests Hypothesis 4.1 that technologically advanced products survive longer. The *advanced product* variable takes a value of one for products with data access time below the industry's mean data access time for a given year. This variable takes a value of zero for products with data access time equal or above the industry's mean data access time for a given year.

We construct two density counts to test Hypothesis 5.1, which predicts the different effects of the two types of products on product population vital rates. *Density of de alio products* is the number of *de alio* products on the market in a given year. *Density of de novo products* is the number of *de novo* products on the market in a given year.

Two variables, that reflect density of technologically advanced products and density of technologically non-advanced products, are created to test Hypothesis 5.2 about the stronger competitive effect of technologically advanced products. *Density of advanced products* is the number of products with data access time below the industry's mean data access time in a given year. *Density of non-advanced products* is the number of products with data access time equal or above the industry's mean data access time in a given year. Four additional variables are created to measure *de novo* and *de alio* density of technologically advanced and non-advanced products to test Hypothesis 5.3: *density of de alio advanced products*, *density of de alio non-advanced products*, *density of de novo advanced products*, and *density of de novo non-advanced products*.

Product controls. As products age, they tend to become technically and even socially obsolete. Obsolescence increases the probability of product exit from the market (Greenstein & Wade, 1998; de Figueiredo & Kyle, 2001). *Product age*, measured as the number of years since a product was first shipped, is controlled for to account for higher exit rates of aging products.

The Disk/Trend report classifies optical disk drives by product groups based on a product's operating mode and recording capacity. It is found that products compete with each other more intensely within product groups than across them (Greenstein & Wade, 1998). We include two groups of variables to control for this possibility: operating mode and recording capacity. *Operating mode* is measured as two sets of dummy variables. The first set of variables measures if drives are designed for read only, write once, or rewritable operation. The *read only*

memory (ROM) dummy takes a value of one for products with read only operating mode, and zero otherwise. The *rewritable (RW)* dummy takes a value of one for products with rewritable operating mode, and zero otherwise. The *write once (WO)* dummy takes a value of one for products with write once read many operating mode, and zero otherwise, and serves as a reference category. The second set of variables specifies a type of product format family. The *CD/DVD/PD family* dummy takes a value of one for products from CD/DVD/PD format family, and zero otherwise. The dummy that takes a value of one for products from other than CD/DVD/PD format family is a reference category. *Recording capacity* indicates how much data can be stored on a disk. It is measured in GBytes. Higher recording capacity improves the market attractiveness of a drive.

Since an optical disk drive is a type of removable storage, it has to be installed internally within the host computer or connected externally to an I/O interface. There are several interfaces, among which, SCSI (Small Computer System Interface) and IDE/ATAPI (Integrated Drive Electronics/Advanced Technology Attached Interface) are the most popular. Interfaces differ by robustness and price. SCSI is very reliable but expensive, whereas IDE/ATAPI is less robust but much cheaper. A type of interface can define to a significant extent the channels of product distribution. SCSI is popular among professional users, IDE/ATAPI is a preferred interface among nonprofessionals. We use two dummy variables to account for the possibility that products with different interfaces can compete more intensively within interface groups than across them. *SCSI* dummy and *IDE/ATAPI* dummy take a value of one for products with corresponding interfaces, and zero otherwise. A dummy, that takes a value of one for products with any other interfaces, serves as a reference category.

Firms can manufacture products either for internal use and/or for sale. The distribution channel – captive or non-captive (PCM and OEM) – can affect the intensity of competition between producers and possibly the life length of their products (McKendrick et al., 2000). The dummy variable *captive*, that takes a value of one if a product is sold through internal channels, and zero if otherwise, is controlled for to account for the possibility of differences in exit chances of products made for different distribution channels.

Environmental controls. Several variables are used to control for industry processes. Unless otherwise noted, all are updated annually. Environmental munificence can affect product market longevity chances, so *worldwide industry revenues* measured in millions of U.S. dollars are controlled for.

The number of products on the market creates competition for a buyer's attention (de Figueiredo & Kyle, 2001; Sorenson, 2000). The time-varying counts of *product density* are created to control for intensity of product competition.

Aside from contemporaneous density, density in the year when a product was first shipped (density delay) may affect subsequent product failure rates. The density delay model was created for the organizational level of analysis (Carroll & Hannan, 1989), but can be extended to the product level of analysis. High densities at the time of the initial product shipment can permanently hamper product success opportunities, because it can be very difficult to get buyers' attention in the densely packed market. Later on, even if the market becomes less packed, products that were unable to get buyers' attention at the time of their appearance on the market, are unlikely to gain it later as well. This happens because the buyers who have to choose between two unknown alternative products are likely to pick a newer one. Thus, product density at the time of a product's first shipment should positively contribute to the product's exit

chances. The variable *product density delay* is defined as product density in the year that a product was first shipped. Its value does not vary with time.

A presence or absence of technological standards may affect market longevity of products. The optical disk drive industry has been always populated by multiple incompatible formats that generated format wars and sometimes reduced industry growth (Disk/Trend Report, 1999; Purcell, 2000). As Figure 1 shows, different formats were introduced almost in every year of industry existence. Some of them were influential, others had hardly any significant impact. Only High Sierra format became a widely adopted industry standard that was formalized as ISO 9660 standard in 1988. *Standard ISO 9660 period dummy*, which takes a value of one for years 1988-1999, and zero otherwise, is created to control for effects of this standard on product exit rates. Effects of other formats are captured by the variable *industry age*, which is the age of the worldwide optical disk drive industry. Industry age variable is also meant to control for other unobserved and observed temporal changes that may affect product chances to disappear from the market.

Model Specification

Product exit/disappearance rates are assessed using continuous-time event history analysis. We treat a product as the unit at risk, and the ‘dependent variable’ is the probability of a product’s exit from the worldwide optical disk drive industry, defined as:

$$r(t) = \lim_{\Delta t \rightarrow 0} \frac{P[t < T < t + \Delta t | T < t]}{\Delta t} ,$$

where T is a random variable for the time of the event of interest, t is the time that a product has existed, and $P(\cdot)$ is the probability of the product’s exit from the market over the interval $[t, t+\Delta t]$ given that the product was still on the market at time t .

We use a *piecewise exponential* function to represent variation in the timing of industry exit to allow a flexible specification of age-dependence:

$$r(t) = \exp\left[\sum_{j=0}^k \alpha_j D_j(t)\right],$$

where $D_j(t) = 1$ when t belongs to interval $(t_j, t_{j+1}]$ and 0 if otherwise. A *piecewise exponential* model represents a widely used strategy that splits the time-axis into time pieces determined by an analyst (Carroll & Hannan, 2000: 150-152, 312-319). After examining life tables and exploring estimates of a variety of choices of the breakpoints, we decided to break the duration scale in years at 1.0, 2.0, 3.0 and 5.0. The first segment $(0,1.0]$ includes dated events that occur within the first year on the market with cases that enter and exit at unknown times within the same year. The second segment $(1.0, 2.0]$ includes dated events that occur within the next year on the market with cases that enter at unknown time in one year and exit at unknown time within the same year. Other segments are from 2 to 3 years, from 3 to 5 years. The final segment begins at 5 years and is open on the right.

The product exit/disappearance rate is specified as a function of product age (u), product contemporaneous density (n_t), product density delay (n_u), *de novo* status (d) and other measured covariates (X). The general class of models we estimate has the form:

$$\ln [exit(u,t)] = m_p + \beta n_{it} + \delta n_{iu0} + \varphi d_i + \gamma X_{it},$$

where m_p denotes age-specific effects, n_{it} denotes product density for product i at year t , n_{iu0} denotes product density for product i at year u_0 of the first shipment, d_i denotes *de novo* status of a firm making product i , and X_{it} summarizes time-varying covariates.

In testing the hypotheses, we estimated models using the method of maximum likelihood as implemented with a user-defined routine in STATA (Sorensen, 1999). To estimate rate

models with time-varying covariates we constructed split-spell data breaking observed durations in year-long periods with values of covariates updated every year.

Results

Table 1 provides descriptive statistics for the key variables. It shows that mean product life on the market is about 17 months (18 months if right-censored cases are not counted) with a standard deviation of 17 months (18 months). Mean *de alio* product life is about 17 months (18 months), mean *de novo* product life is about 15 months (15 months), with about the same standard deviation of 17-18 months (18 months). The shortest-lived *de alio* product stayed on the market for about 1 month (1 month); the shortest-lived *de novo* product stayed on the market for about 2 months (2 months). The oldest *de alio* product stayed on the market for about 10 years (10 years); the oldest *de novo* product exited the market after about 8.4 years (8.4 years). From 1983 to 1999, 1,219 *de alio* and 139 *de novo* products were shipped on the worldwide optical disk drive market, of which 939 *de alio* and 114 *de novo* products exited the market. The data include 3,078 (2,805 *de alio* and 273 *de novo*) product-firm-year observations.

[Table 1 about here]

To test Hypothesis 1 that *de alio* firms ship more product models than *de novo* firms, we looked at descriptive statistics of the variables measuring the number of products shipped by the two types of entrants in a given year. As Figure 5 shows, the mean annual number of products shipped by *de alio* firms is 5.15 with standard deviation of 6.11, whereas the mean annual number of products shipped by *de novo* firms is 2.7 with standard deviation of 1.72. Variance for *de alio* firms is 37.31 products, for *de novo* firms is 2.97 products. Skewness and kurtosis are significantly larger for *de alio* firms. Mean comparison test (t-test) indicates a significant difference in the mean number of products shipped by *de novo* and *de alio* firms ($t = 3.99$; $p <$

.0001). Thus, although *de alio* firms show higher variance in the number of product shipped, it is still possible to conclude that, on average, they ship more products than *de novo* firms. Figure 5 that plots the number of products shipped by *de alio* and *de novo* firms by year visually confirms this conclusion.

[Figure 5 about here]

Table 2 presents the estimates of piecewise-exponential rate models of the exit of products from the worldwide optical disk drive market from 1983 through 1999. Table 2 demonstrates how organizational and product property differences between *de alio* and *de novo* products affect their market exit rates. Model 2.1 provides a baseline for the key covariates influencing product exit including product age, contemporaneous product density, product density at first shipment, industry revenues, industry age, and standard ISO 9660 period dummy. The estimates reveal positive age-dependence of product exit, where the disappearance rate of individual products significantly increases with their tenure on the market. This finding of positive age-dependence is consistent with previous empirical research on product fates (Greenstein & Wade, 1998; de Figueiredo & Kyle, 2001). Density of all products has a significant competitive effect reducing chances of products to stay on the market. As predicted, product density at the year of first shipment has a significantly strong positive effect on exit: the higher the product density in the year that the product was introduced to the market, the higher its disappearance chances. Worldwide industry revenues have a predicted significant negative impact on product exit. The period dummy designated to detect effects of standard ISO 9660 is not significant. Industry age shows a large significant negative effect on the probability of product exit. A plausible explanation for such a large effect is that as the industry has evolved, customer acceptance of a new product and demand for this product were developed. The

literature on innovation suggests that adoption of new technology by a large number of customers and the consequent creation of standards prolongs product market life span (Tushman & Anderson, 1986; Gort & Klepper, 1982; Klepper, 1997). The finding of a negative impact of industry age on product exit is largely consistent with this literature.

[Table 2 about here]

Model 2.2 tests Hypothesis 2 that *de alio* products are likely to stay on the market longer than *de novo* ones. This hypothesis is strongly supported: *de novo* products have a much higher probability of exiting the market than *de alio* products. Figure 6a shows that gap between *de novo* and *de alio* product exit rates dramatically increases with increasing product age. Figure 6b demonstrates that the gap between *de novo* and *de alio* products' chances of staying on the market drastically increases with increasing product density. This finding is largely consistent with the innovation literature, which suggests that start-ups play a more profound role at the beginning of industries but tend to lose their leadership to established firms as industries evolve (Freeman & Soete, 1999). Model 2.2 (Chi-square of 680.80 with 10df) is a great improvement over Model 2.1 (Chi-square of 664.38 with 9df).

[Figures 6a and 6b about here]

Models 2.3-2.4 test Hypothesis 3.1, which predicts that the products with performance parameters closer to either the top or bottom frontiers have higher market longevity rates. We use data access time as a performance parameter. Model 2.3 shows that the greater a product's data access time (e.g., the slower its performance), the higher its exit chances. This effect is statistically significant.

The square term of data access time is added in Model 2.4 to test the prediction about a bottom technological frontier. Model 2.4 provides a better fit (Chi-square of 695.58 with 12df)

than Model 2.3 (Chi-square of 641.67 with 11df). The estimates of the linear and squared terms of data access time are significant and in the predicted direction: the closer the product to either the top or bottom frontier, the higher its market longevity rates. This nonlinear effect is within the observed range of product data access time: .078-7.99. The turning point for a nonlinear effect is calculated with formula: $AT^* = -\beta_{AT} / 2\beta_{AT}^2 = -.732/2*(-.124) = 2.95$. The turning point indicates that product exit rates increase with increasing product data access time (increasing distance from the top frontier) to the point when data access time reaches 2.95, then product exit rates decrease with further increasing data access time (decreasing distance to the bottom frontier). Thus, both the top and bottom technological frontiers matter significantly in predicting how a product's performance affects its chances of staying on the market. Hypothesis 3.1 is supported. Although the proximity to either the top or bottom frontier is associated with lower product disappearance rates, the negative effect on product exit is six times greater for products with data access time closer to the top frontier, than for those with data access time closer to the bottom frontier.

A possible explanation for the findings about product performance proximity to those of technological frontiers can be derived from the study of Barnett & McKendrick (2001) who shown that hard disk drive manufacturers competing at technological edges face less competition than manufacturers competing in the middle of performance distribution. Based on that study it is possible to suggest that products with performance parameters close to those of technological frontiers stay on the market longer because they face fewer competitors.

Model 2.5 tests Hypotheses 3.2 and 3.3. Specifically, it examines how effects of proximity of product performance to the dual technological frontiers differ for *de novo* and *de alio* products. Model 2.5 adds interactions of product access time and its square term with *de*

novo dummy. The estimates of data access time for *de alio* products are significant and in the predicted direction. These results support Hypothesis 3.2: the closer data access time of *de alio* products to either the top or bottom frontier, the higher these products' market longevity chances. While the linear term for data access time of *de novo* products is significant, the square term is significant only marginally ($p < .06$). These results provide a moderate support for Hypothesis 3.3, because, *de novo* products seem to have significantly better market longevity chances when their data access time is closer to the top frontier, and only marginally significant better longevity chances when their data access time is closer to the bottom frontier.

Figure 7 graphically illustrates how proximity of product performance to the dual frontiers affect exit rates of *de novo* and *de alio* products at the mean level of product density. Nonlinear effects of data access time for the both types of entrants are within the range of the observed data access time. For *de novo* products, the turning point of 1.15 is within the observed range of *de novo* data access time .130-2.59. For *de alio* products, the turning point of 2.96 is within the observed range of *de alio* product data access time .078-7.99.

The figure provides three important observations. First, *de alio* products represent a wider range of performance distribution than *de novo* products. Apparently, *de alio* firms have a larger product base and drop unprofitable products slower than the *de novo* firms. This difference points out on the greater propensity of *de alio* firms to pursue product differentiation strategy. Second, *de novo* and *de alio* products have different bottom frontiers. *De novo* firms offer products with better performance parameters at the bottom frontier than *de alio* firms. It looks that *de alio* firms have a greater tolerance to the introduction of products with low performance parameters than *de novo* firms. It is possible that they have more resources and can bear greater risk of manufacturing low-performance products. Third, the effect of performance proximity of

products to the dual frontiers is somewhat more pronounced for exit rates of *de alio* products than *de novo* products. Increasing distance of a *de alio* product's data access time from either frontier significantly increases its market exit rates. This effect is greater than the same effect for *de novo* products.

A possible explanation for the three observations provided by Figure 7 is that *de novo* firms make products that can successfully compete over narrower range of performance distribution than products made by *de alio* firms. In other words, the product range, over which *de novo* firms can be profitable, are much narrower than the one, over which *de alio* firms can be profitable.

[Figure 7 about here]

Model 2.6 tests Hypothesis 4.1 that technologically advanced products stay on the market longer than non-advanced ones. This model demonstrates a strong significant negative effect of the advanced product dummy on product exit rates. This result indicates that products with data access time better than the industry's mean have lower disappearance rates than products with data access time equal to or worse than the industry's mean. Model 2.6 provides a better fit (Chi-square of 707.75 with 15df) than Model 2.5 (Chi-square of 700.6 with 14df). The model not shown here tested potential differences between *de alio* and *de novo* advanced products but failed to get significant results. Thus, Hypothesis 4.1 is strongly supported, while Hypothesis 4.2 is rejected.

Table 3 builds on the previous analysis of differences in fates of *de novo* and *de alio* products to examine the roles of *de novo* and *de alio* optical disk drives in the industry competitive processes. Models in Table 3 maintain the same baseline covariates as the earlier models but separate out the effects of *de novo* and *de alio* densities and densities of advanced

and non-advanced products rather than aggregating them into one total density count. All non-density covariates have the same effects as in the earlier models.

[Table 3 about here]

Model 3.1 builds on Model 2.2 such that the variable of all product density is separated out into density of *de alio* and density of *de novo* products. Model 3.1 shows that density of *de alio* products generates a strong competitive pressure on all products significantly increasing their exit rates. The effect of *de novo* density is not significant. This finding supports Hypothesis 5.1.

Model 3.2 adds product performance variables and the advanced product dummy. All effects are as predicted. Density of *de alio* firms still exerts a strong competitive effect, whereas the effect of *de novo* density is still not significant. Model 3.2 provides a better fit (Chi-square of 703.18 with 14df) than Model 3.1 (Chi-square of 681.25 with 11df).

In Model 3.3, the densities of *de novo* and *de alio* products are replaced by two new time-variant variables: density of advanced products and density of non-advanced products. The first variable includes all products with data access time below the industry's mean in a given year. The second variable includes all products with data access time equal or above the industry's mean in a given year. Only density of technologically advanced products shows a statistically significant positive effect on the exit rates of all products. In substantive terms, the competitive pressure of technologically advanced products is four times greater than that of technologically non-advanced products. These results support Hypothesis 5.2.

Model 3.4 tests Hypothesis 5.3, which proposes a difference between effects of technologically advanced and non-advanced *de novo* and *de alio* products. The results indicate that *de alio* advanced products exert the strongest competitive pressure on population members.

Effects of *de alio* non-advanced and *de novo* advanced and non-advanced products are not significant. Figure 8 demonstrates the drastic effect of *de alio* advanced products on all product exit rates in comparison with effects of *de alio* non-advanced products and *de novo* advanced and non-advanced products. This effect dramatically increases with increasing all product density.

[Figure 8 about here]

Model 3.5 includes controls for product groups distinguished on the basis of operating mode and recording capacity. Including these controls renders the data access time variables insignificant. Model 3.6 is the same as Model 3.5 but excludes data access time variables. In this model, again only the density of *de alio* advanced products generates a strong effect, which is competitive. All control variables are statistically significant, which indicates that competition within product groups is stronger than across product groups. Drives from CD, DVD, and PD families have lower exit rates than those from other families. Read Only Memory drives have higher disappearance rates than Write Once drives. Rewritable drives have lower disappearance rates than Write Once drives. Drives with greater recording capacity stay on the market longer. Model 3.6 is a significant improvement (Chi-square of 776.02 with 18df) over Model 3.4 (Chi-square of 704.97 with 16df).

Model 3.7 includes controls for a type of interface and distribution channel. None of these estimates is statistically significant, which indicates that neither type of interface nor distribution channel matters for market longevity of optical disk drives. All other estimates maintain the same effects as in Model 3.6. Model 3.7 is not an improvement (Chi-square of 765.08 with 21df) over Model 3.6 (Chi-square of 776.02 with 18df). Thus, Models 3.5-3.7 consistently indicate that *de alio* advanced products generate significant competitive pressure on all products, while *de alio* non-advanced and all *de novo* products do not.

DISCUSSION

The organizational literature shows that *de novo* and *de alio* firms are different. They face different initial conditions when they enter markets and industries (Bruderl, & Schussler, 1990; Klepper & Simons, 2000). They tend to engage in different types of innovation activity (Anderson & Tushman, 1990, Henderson & Clark, 1990). They experience different organizational fates (Mitchell, 1994; Carroll, et al., 1996). The contribution of this study is the demonstration that *de novo* and *de alio* firms are also different in the ecological dynamics of their products. The key idea of the concept developed in this paper is that different initial conditions faced by *de novo* and *de alio* firms create an organizational propensity to engage in certain types of innovation. Consequently, the product dynamics of *de novo* and *de alio* firms are very different as well that can be a key reason for different firm-level outcomes.

Using the worldwide optical disk drive industry as a setting for testing the concept developed in this paper, we present four main findings. First, *de alio* firms ship more product models than *de novo* firms. Second, *de alio* firms compete over a wider range of product performance distribution than *de novo* firms. Third, the products made by *de alio* firms have higher market longevity rates (higher chances of staying on the market longer) than those made by *de novo* firms. Finally, products made by *de alio* firms (especially technologically advanced *de alio* products) generate strong competitive pressure on all products on the market, whereas products made by *de novo* firms do not.

Overall, these findings suggest that in capital intensive industries with standardization issues, entry conditions drive the ecological processes at the product-level that create an advantage for *de alio* firms from related industries. As a result, *de alio* firms often enjoy higher performance and survival rates. This points out that product-level dynamics is likely to be an

important mediating mechanism between *de novo* and *de alio* firms' initial entry conditions, their propensity to innovate, and the organizational fates of the two types of producers.

Contributions

This study has important conceptual and practical implications. First, it is one of the few studies that examine the ecology of products (for an exception see Greenstein & Wade, 1998; de Figuerado & Kyle, 2001). Ecological dynamics of products is a young area of research. This study further contributes to the previous research by discovering new factors, like for example, density delay, that significantly shape the vital dynamics of products. Second, but probably the most important contribution of this study is the demonstration that the ecological dynamics are different for products made by *de novo* firms and products made by *de alio* producers. This finding can be the first step toward understanding the mechanisms that link together firms' entry conditions and their fates.

On the practical side, this study may have strategic implications. As the results of this research show, entry status shapes to a great extent what product strategies are likely to be successful and what are not. For example, start-up firms are more likely to have products with longer market life if they compete over narrowly focused range of performance distribution. Their products are more likely to be doomed if they try to compete over wide range of technological performance distribution as *de alio* producers do. Understanding limitations in the choice of a product strategy based on a firm's entry conditions could be a valuable knowledge for the managers who design firm strategy.

Limitations and Directions for the Future Research

This study has several limitations. The first important limitation is that the test of the developed concept is limited to only one organizational population – the worldwide optical disk

drive industry. There are advantages and disadvantages of using this industry for the analysis. First, this industry is capital intensive. Since it was found that innovation activity of *de novo* and *de alio* firms can differ in industries of high and low capital intensity (Freeman & Soete, 1999), the findings of this study are not likely to reflect product dynamics in industries with low capital intensity. A test of the concept developed in this paper on a less capital intensive industry is necessary to further understand the dynamics of *de alio* and *de novo* products. Second, *de alio* firms from related industries have always dominated the optical disk drive industry. Therefore, it is not surprising that *de alio* products are stronger survivors and competitors. To insure generalizability of the new concept it is necessary to see if it still holds in the industries where *de novo* firms play a more significant role. Third, the optical disk drive industry has been an arena for format wars. Standards play a profound role in this industry. The findings of this study might not generalize to industries where standards play a less prominent role or industries with an established dominant design. Finally, the optical disk drive industry is relatively young. The dynamics of *de alio* and *de novo* products in mature industries may differ from the ones described in this study. Further research is necessary to establish if this is the case or not.

The second limitation of this study is that it conceptually assumes but does not test directly whether and to what extent the product-level processes are of consequences to firm-level outcomes. It is necessary to conduct the analysis that links together fates of *de alio* and *de novo* products and fates of *de alio* and *de novo* firms in order to pervasively demonstrate that discovered in this study processes at the product level strongly affect processes at the organizational level. This is a goal for the next step of our research agenda of understanding the dynamics of differences between *de alio* and *de novo* organizations.

Conclusion

The interaction between *de alio* and *de novo* firms shape competitive landscapes of industries. Yet the mechanisms of this interaction are not well understood. This study highlights one of such mechanisms – the ecological dynamics of products made by the two types of entrants. The analysis of the optical disk drive industry presented in this paper demonstrated that behavior and fates of *de novo* and *de alio* products are significantly different. These differences shape not just competitive dynamics of product population but may have important implications for fates of firms producing them. Given that, further exploration of how product dynamics and why differ for *de novo* and *de alio* firms is necessary. This stream of research promises to be fruitful and enlightening for understanding differences between the two types of entrants and processes of their interaction.

Figure 1. Historical Summary of Optical Data Storage Technology

- 1972 Philips announces optical storage method for audio
- 1978 Sony and Philips collaborate on signal format and disk material
- 1980 Compact Disc Digital Audio (CD-DA) system standard developed by Sony and Philips is adopted
- 1983 Compact Disc is introduced in the United States
- 1984 CD-ROM (Compact Disk–Read Only Memory) format is introduced
- 1986 High Sierra format is established
- 1986 CD-I (Compact Disk-Interactive) standard developed by Philips is released
- 1988 The standard (ISO 9660) for file structure of CD-ROM for information interchange is adopted
- 1988 The first rewritable optical format is introduced
- 1992 Optical Storage Technology Association (OSTA) is established to help the creation of optical standards
- 1993 CD-R (Compact Disk – Write Once) format is introduced by Philips
- 1994 Video-CD format is introduced
- 1995 DVD Consortium (DVD Forum since 1997) is established to define DVD standards
- 1996 DVD (Digital Versatile Disk) format is agreed upon
- 1996 CD-RW (Compact Disk–Rewritable) format emerges as a result of collaboration between Hewlett-Packard, Mitsubishi Chemical Corporation, Philips, Ricoh, and Sony
- 1997 DVD-ROM (read only) drives become available
- 1997 OSTA develops MultiRead specifications and test plans for compatibility among CD-DA, CD-ROM, CD-R, CD-R/RW & DVD-ROM devices
- 1997 DVD-R (write once) format appears
- 1997 DVD-RAM (rewritable) format is released by Hitachi, Matsushita Electric and Toshiba
- 1997 DVD+RW (rewritable) format is released by Sony, Philips & Hewlett-Packard
- 1999 OSTA develops MultiRead2 specifications and test plans for compatibility among CD-ROM, CD-R, CD-R/RW, DVD-Video, DVD-Audio, DVD-ROM and DVD-RAM drives
- 2000 17 CD drive manufacturers, representing well over 90 percent of all CD optical drive shipments worldwide, have achieved compliance with MultiRead specification developed by OSTA

Figure 2a. Density of Firms by Entrant Type

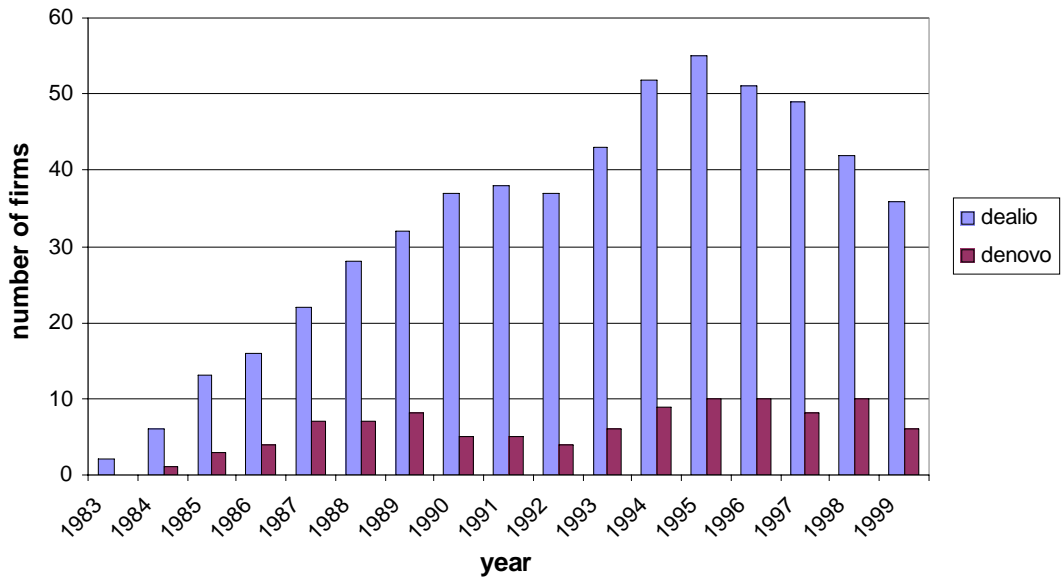


Figure 2b. Density of Products by Entrant Type

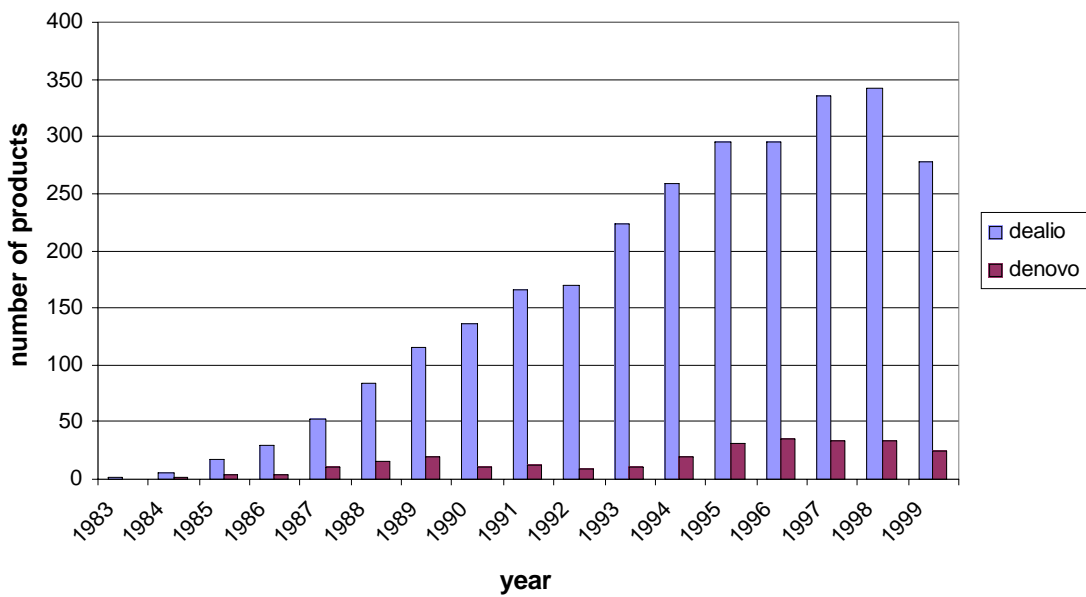


Figure 3. Conceptual Model of Differences between *De Novo* and *De Alio* Fates

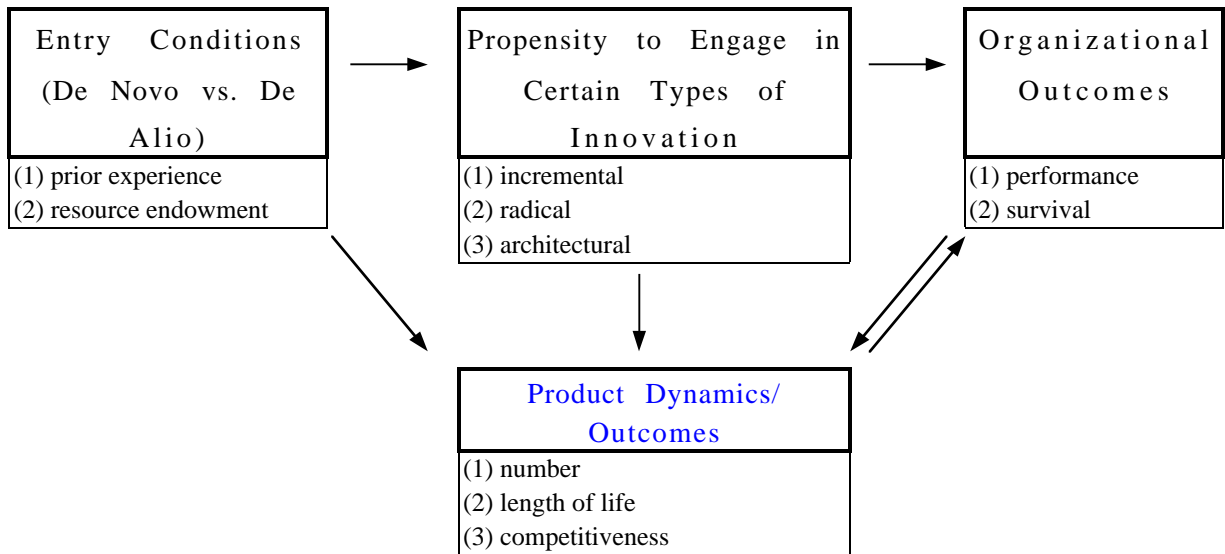


Figure 4. Mean Product Data Access Time by Entrant Type

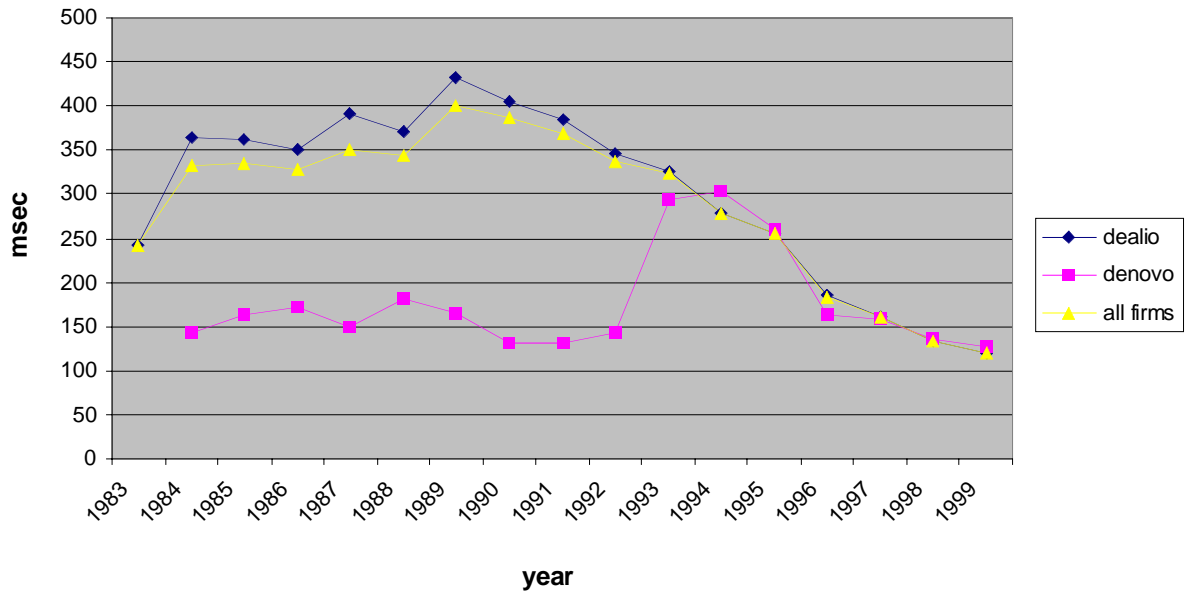


Figure 5. Number of Products by Firm Entry Status by Year

Variable	Mean	Std. Dev	Min	Max	Variance	Skewness	Kurtosis
Number of Products by <i>De Novo</i> Firms (t)	2.70	1.72	1	7	2.97	.819	2.74
Number of Products by <i>De Alio</i> Firms (t)	5.15	6.11	1	43	37.31	3.04	15.01

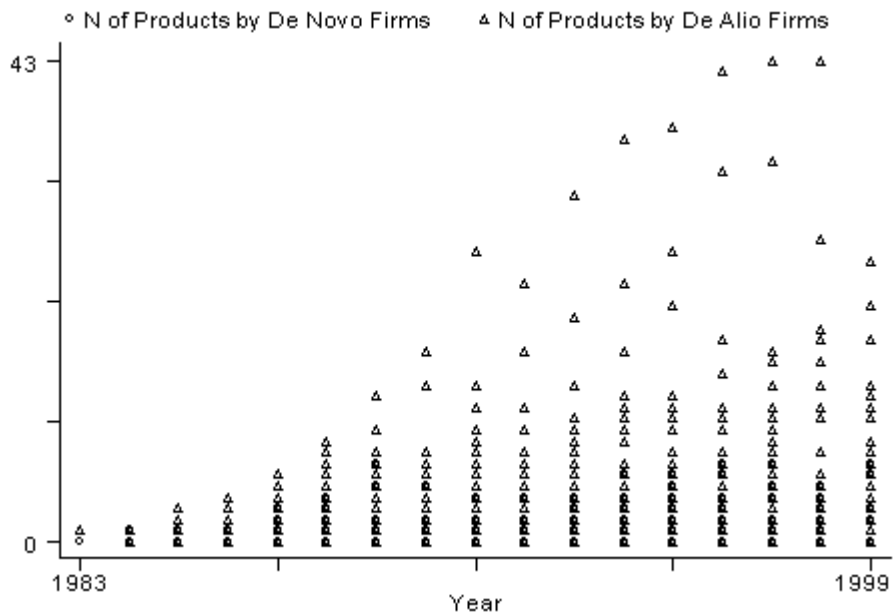


Figure 6a. Joint Effect of Firm Entry Status and Product Age on Product Exit Rates at the Mean Level of Product Density

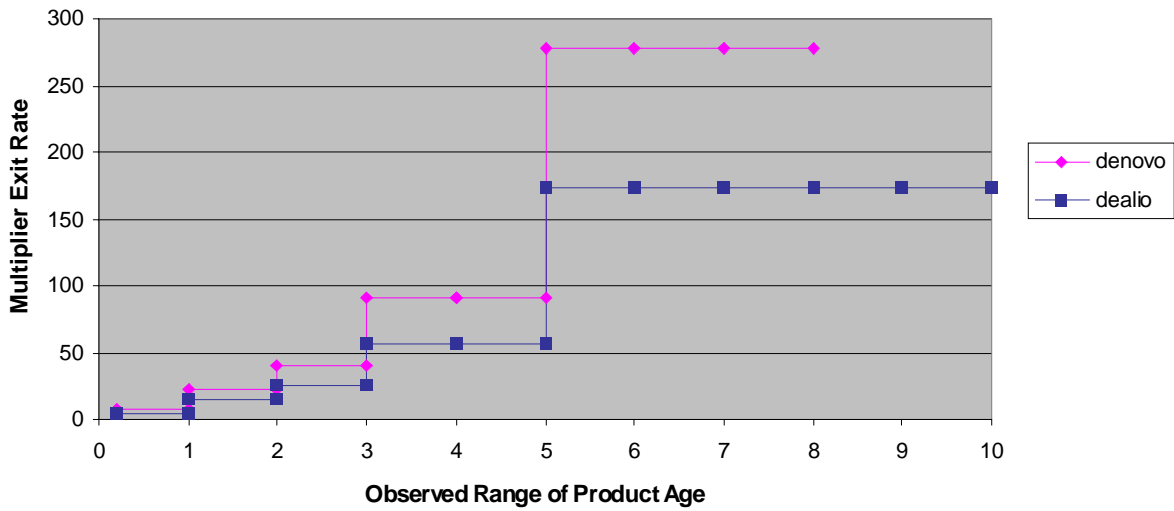


Figure 6b. Joint Effect of Firm Entry Status and Product Density on Product Exit Rates

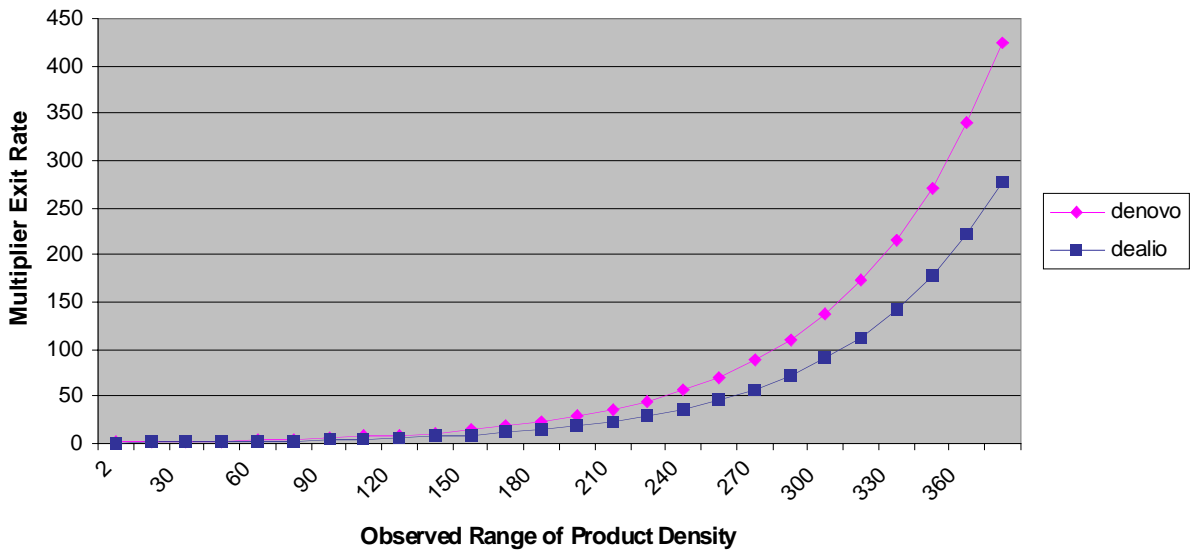


Figure 7. Effect of Standardized Data Access Time on *De Alio* and *De Novo* Product Exit Rates at the Mean Level of Product Density

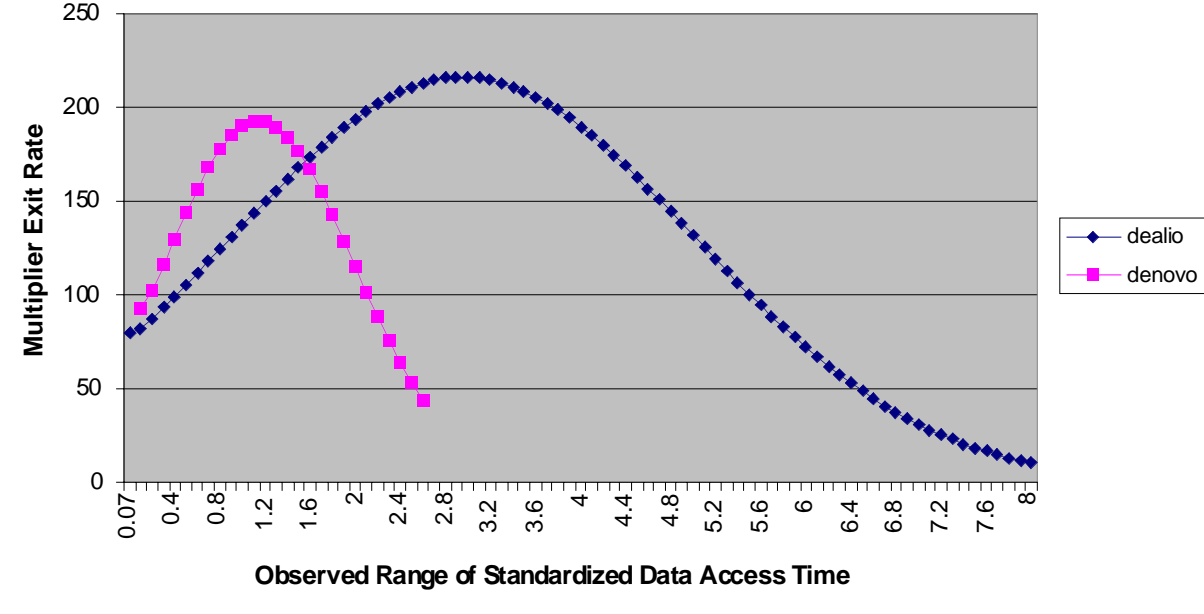


Figure 8. Effects of Densities of Advanced and Non-Advanced Products by Entrant Type on Product Exit Rate

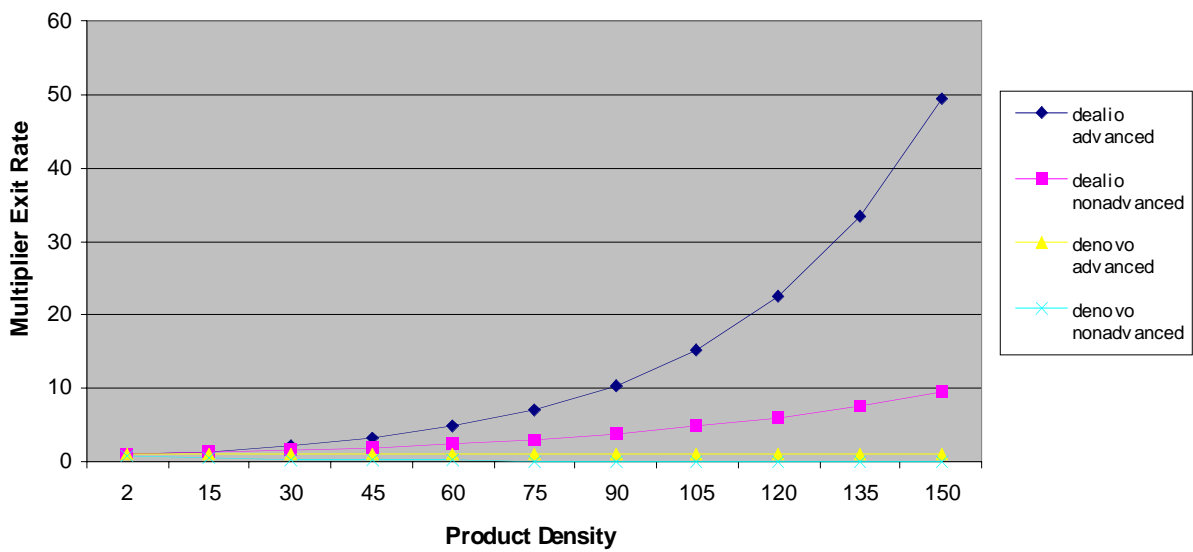


Table 1. Descriptive Statistics for Optical Disk Drives (Products) Exit Split-Spell File

Variable	Mean	Std. Dev	Min	Max
Failure = 1	.342	.475	0	1
Product Age (u)	1.45 (1.51) ¹	1.45 (1.52)	.042 (.042)	10.0
<i>De Novo</i> Product Age	1.29 (1.22)	1.53 (1.52)	.125 (.125)	(10.0)
<i>De Alio</i> Product Age	1.47 (1.55)	1.44 (1.51)	.042 (.042)	8.38 (8.38) 10.0 (10.0)
Density All Products (t)	270.9	94.6	2	375
Product Density Delay (u_0)	246.3	110.7	2	375
Industry Revenues (t) [in millions of US dollars]	5,099	3,778	2	10,068.3
Industry Age (t)	11.36	3.50	0	16
Period Dummy for Standard ISO9660 (1988-1999) =1	.959	.198	0	1
<i>De Novo</i> Status = 1	.089	.284	0	1
Data Access Time [in msec]	252.3	279.4	24	2510
Data Access Time standardized	1	.901	.078	7.99
<i>De Novo</i> Data Access Time standardized	.813	.476	.130	2.59
<i>De Alio</i> Data Access Time standardized	1.02	.930	.078	7.99
Advanced Product Dummy =1	.612	.487	0	1
Density of <i>De Alio</i> Products (t)	247.5	86.1	2	342
Density of <i>De Novo</i> Products (t)	23.4	9.84	0	35
Density of All Advanced Products (t)	145.7	46.9	1	200
Density of All Non-Advanced Products (t)	93.7	30.7	1	125
Density of <i>De Alio</i> Advanced Products (t)	132.4	43.2	1	179
Density of <i>De Alio</i> Non-Advanced Products (t)	85.8	25.7	1	110
Density of <i>De Novo</i> Advanced Products (t)	13.3	5.6	0	21
Density of <i>De Novo</i> Non-Advanced Products (t)	7.9	5.5	0	15
Operating Mode: Read Only Memory =1	539.5	.499	0	1
Operating Mode: Rewritable = 1	.265	.442	0	1
Operating Mode: Write Once = 1	.229	.420	0	1
Operating Mode: CD/DVD/PD family =1	.468	.499	0	1
Recording Capacity [in Gbytes]	1.16	2.10	.122	25
Interface: SCSI =1	.570	.495	0	1
Interface: IDE/ATAPI =1	.339	.473	0	1
Interface: Others =1	.194	.396	0	1

¹ Numbers in parentheses are calculated for uncensored cases only. Numbers that are not in parentheses are based on both uncensored and right-censored cases.

Distribution Channel: Captive =1 .173 .378 0 1

N of products = 1,358 (*de alio*=1,219; *de novo*=139); N of exits=1,053 (*de alio*=939; *de novo*=114); N of product-years =3,078 (*de alio*=2,805; *de novo*=273)

Table 2. Estimates of Piece-wise Constant Rate Models of Exit/Disappearance of Optical Products (Standard errors shown in parentheses)

	Model (2.1)	Model (2.2)	Model (2.3)	Model (2.4)	Model (2.5)	Model (2.6)
Product Age: $0 < u \leq 1$	-2.51*** (.442)	-2.63*** (.443)	-2.92*** (.449)	-3.44*** (.456)	-3.39*** (.457)	-2.89*** (.492)
Product Age: $1 < u \leq 2$	-1.30** (.448)	-1.40** (.449)	-1.73*** (.455)	-2.23*** (.461)	-2.16*** (.463)	-1.68** (.497)
Product Age: $2 < u \leq 3$	-.720 (.464)	-.826 (.466)	-1.20* (.473)	-1.63** (.477)	-1.55** (.479)	-1.05* (.514)
Product Age: $3 < u \leq 5$	.091 (.489)	-.030 (.491)	-.439 (.500)	-.824 (.504)	-.740 (.506)	-.234 (.541)
Product Age: $u > 5$	1.24* (.550)	1.09* (.554)	.614 (.565)	.225 (.571)	.317 (.574)	.857 (.609)
Density All Products (t)	.015*** (.002)	.015*** (.002)	.016*** (.002)	.016*** (.002)	.016*** (.002)	.016*** (.002)
Density Delay All Products at u_0	.020*** (.002)	.020*** (.002)	.019*** (.002)	.019*** (.002)	.019*** (.002)	.019*** (.002)
Worldwide Industry Revenues (t) [in millions of US dollars]	-.0003*** (.000)	-.0003*** (.000)	-.0003** (.000)	-.0004*** (.000)	-.0004*** (.000)	-.0003*** (.000)
Industry Age/ Year	-.633*** (.089)	-.613*** (.089)	-.556*** (.093)	-.539*** (.091)	-.546*** (.092)	-.558*** (.092)
Standard ISO9660 period dummy =1	.133 (.448)	.106 (.448)	-.035 (.451)	-.037 (.450)	-.005 (.450)	-.036 (.450)
<i>De Novo</i> Status =1		.427*** (.099)	.475*** (.103)	.469*** (.103)	-.259 (.369)	-.243 (.366)
Product's Access Time (t) [standardized]			.148*** (.027)	.732*** (.089)	.704*** (.092)	.418** (.138)
Product's Access Time ² (t) [standardized]				-.124*** (.020)	-.119*** (.020)	-.078** (.024)
Product's Access Time * <i>De Novo</i> Status					1.62* (.762)	1.60* (.772)
Product's Access Time ² * <i>De Novo</i> Status					-.707^ (.370)	-.734^ (.381)
Advanced Product dummy = 1						-.315** (.118)

No. of Exits	1053	1053	958	958	958	958
No. of Products	1358	1358	1196	1196	1196	1196
No. of Product-Year Spells	4435	4435	4019	4019	4019	4019
Log L	-1490.81	-1482.60	-1322.73	-1295.78	-1293.27	-1289.69
Chi Square vs. null rate	664.38 (9d.f.)	680.80 (10d.f.)	641.67 (11d.f.)	695.58 (12d.f.)	700.6 (14d.f.)	707.75 (15d.f.)
<hr/> $p^{\wedge} < .06$; $p^* < .05$; $p^{**} < .01$; $p^{***} < .001$ <hr/>						

**Table 3. Estimates of Piece-wise Constant Rate Models of Exit/Disappearance of Optical Products
(Standard errors shown in parentheses)**

	Model (3.1)	Model (3.2)	Model (3.3)	Model (3.4)	Model (3.5)	Model (3.6)	Model (3.7)
Product Age: $0 < u \leq 1$	-2.46*** (.509)	-2.80*** (.561)	-3.04*** (.490)	-2.49*** (.567)	-4.53*** (1.10)	-4.55*** (1.08)	-4.55*** (1.09)
Product Age: $1 < u \leq 2$	-1.23* (.518)	-1.60** (.569)	-1.85*** (.494)	-1.29* (.575)	-3.20** (1.10)	-3.23** (1.09)	-3.21** (1.09)
Product Age: $2 < u \leq 3$	-.649 (.534)	-.981 (.585)	-1.24* (.511)	-.671 (.593)	-2.53* (1.11)	-2.56* (1.10)	-2.51* (1.11)
Product Age: $3 < u \leq 5$	.148 (.558)	-.163 (.610)	-.429 (.538)	.148 (.616)	-1.64 (1.13)	-1.69 (1.12)	-1.64 (1.12)
Product Age: $u > 5$	1.28* (.623)	.934 (.681)	.653 (.608)	1.26 (.684)	-.564 (1.17)	-.620 (1.16)	-.572 (1.16)
Density Delay All Products at u_0	.020*** (.002)	.019*** (.002)	.019*** (.002)	.019*** (.002)	.019*** (.002)	.019*** (.002)	.020*** (.002)
Worldwide Industry Revenues (t) [in millions of US dollars]	-.0003** (.000)	-.0003*** (.000)	-.0003*** (.000)	-.0001 (.000)	-.0001 (.000)	-.0001 (.000)	-.0001 (.000)
Industry Age/ Year	-.670*** (.123)	-.593*** (.128)	-.507*** (.089)	-.725*** (.141)	-.589*** (.151)	-.590*** (.151)	-.591*** (.152)
Standard ISO9660 period dummy =1	.174 (.461)	-.020 (.462)	-.078 (.450)	-.060 (.498)	1.87 (1.05)	1.87 (1.05)	1.85 (1.05)
<i>De Novo</i> Status =1	.429*** (.099)	.467*** (.103)	.463*** (.103)	.469*** (.103)	.354** (.111)	.367*** (.110)	.330** (.114)
Density of All <i>De Alio</i> Products (t)	.017*** (.003)	.017*** (.003)					
Density of All <i>De Novo</i> Products (t)	-.009 (.009)	-.011 (.009)					
Product's Access Time (t) [standardized]		.435** (.138)	.421** (.139)	.429** (.139)	.023 (.149)		
Product's Access Time ² (t) [standardized]		-.081** (.024)	-.079** (.024)	-.080** (.024)	-.014 (.024)		
Advanced Product dummy (t)		-.321** (.118)	-.333** (.118)	-.327** (.118)	-.323** (.118)	-.292*** (.081)	-.301*** (.082)
Density of All Advanced Products (t)			.021*** (.003)				
Density of All Non-Advanced Products (t)			.005 (.003)				

Density of <i>De Alio</i> Advanced Products (t)				.026*** (.004)	.023*** (.005)	.023*** (.005)	.023*** (.005)
Density of <i>De Alio</i> Non-Advanced Products (t)				.015 (.011)	.002 (.011)	.002 (.011)	.002 (.011)
Density of <i>De Novo</i> Advanced Products (t)				.001 (.012)	.002 (.012)	.003 (.012)	.004 (.012)
Density of <i>De Novo</i> Non-Advanced Products (t)				-.031 (.030)	.018 (.031)	.019 (.031)	.020 (.031)
Operating Mode: Read Only Drives					.761*** (.098)	.765*** (.097)	.699*** (.105)
Operating Mode: Rewritable Drives					-.581*** (.135)	-.599*** (.131)	-.604*** (.132)
Operating Mode: CD/DVD/PD family					-.573*** (.132)	-.599*** (.130)	-.629*** (.134)
Recording Capacity					-.103*** (.025)	-.102*** (.025)	-.107*** (.026)
Interface: SCSI							-.079 (.109)
Interface: IDE ATAPI							.096 (.112)
Captive							.123 (.107)
No. of Exits	1053	958	958	958	857	857	844
No. of Products	1358	1196	1196	1196	1092	1092	1078
No. of Product-Year Spells	4435	4019	4019	4019	3802	3802	3763
Log <i>L</i>	-1482.38	-1291.98	-1293.13	-1291.09	-1072.92	-1074.15	-1055.41
Chi Square vs. null (constant rate)	681.25 (11d.f.)	703.18 (14d.f.)	700.87 (14d.f.)	704.97 (16d.f.)	778.48 (20d.f.)	776.02 (18d.f.)	765.08 (21d.f.)

p* < .05; p** < .01; p*** < .001

References

- Aldrich, H. E. & Fiol, E.R. (1994). Fools rush in? The institutional context of industry creation. Academy of Management Review, 19: 645-70.
- Anderson, P. & Tushman, M. (1990). Technological discontinuities and dominant designs: A cyclical model of technological change. Administrative Science Quarterly, 35: 604-633.
- Barnett, W.P. & Freeman, J. (2001). Too much of a good thing? Product proliferation and organizational failure. Organization Science, forthcoming.
- Barnett, W.P. & McKendrick, D.G. (2001). The organizational evolution of global technological competition. Report 2001-02, Information Storage Industry Center, U.C. San Diego.
- Bruderl, J. & Schussler, R. (1990). Organizational mortality: the liabilities of newness and adolescence. Administrative Science Quarterly, 35:530-47.
- Carroll, G.R., Bigelow, L.S., Seidel, M-D.L. & Tsai, L.B. (1996). The fates of *de novo* and *de alio* producers in the American automobile industry 1885-1981. Strategic Management Journal, 17: 117-137.
- Carroll, G.R. & Teo, A.C. (1996). Creative self-destruction among organizations: An empirical study of technical innovation and organizational failure in the American automobile industry, 1885-1981. Industrial and Corporate Change, 5: 619-644.
- Carroll, G.R. & Hannan, M.T. (1989). Density delay in the evolution of organizational populations: A model and five empirical tests. Administrative Science Quarterly, 34:411-430.
- Carroll, G.R. & Hannan, M.T. (2000). The Demography of Corporations and Industries. Princeton Press.
- Christensen, C.M. & Bower, J. L. (1996). Customer power, strategic investment, and the failure of leading firms. Strategic Management Journal, 17: 197-218.
- Christensen, C.M. & Rosenbloom, R.S. (1995). Explaining the attacker's advantage: Technological paradigms, organizational dynamics, and the value networks. Research Policy, 24: 233-257.
- Cohen, W. (1995). Empirical studies of innovative activity. In Paul Stoneman (ed.) Handbook and the Economics of Innovation and Technological Change. Blackwell Publishers, Ltd.
- Cohen, W. M. & Levinthal, D.A. (1990). Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly, 35: 128-152.
- Disk/Trend (1985-1999). Disk/Trend Report: Optical Disk Drives. Mountain View, CA: Disk/Trend, Inc.
- Dowell, G. & Swaminathan, A. (2000). Racing and back-peddalling into the future: New product introduction and organizational mortality in the US bicycle industry, 1880-1918. Organization Studies, 21(2): 405-431.
- de Figueiredo, J.M. & Kyle, M.K. (2001). Competition, innovation, and product exit. MIT Working Paper.

- Freeman, C. & Soete, L. (1999). The Economics of Industrial Innovation. Third Edition. Cambridge, MA: MIT Press.
- Gort, M. & Klepper, S. (1982). Time paths in the diffusion of product innovations. The Economic Journal, 92: 630-653.
- Greenstein, S.M. & Wade, J.B. (1998). The product life cycle in the commercial mainframe computer market, 1968-1982. Rand Journal of Economics, 29: 772-789.
- Hannan, M.T. & Freeman, J. (1984). Structural inertia and organizational change. American Sociological Review, 49: 149-164.
- Hannan, M.T. & Freeman, J. (1989). Organizational Ecology. Cambridge, MA: Harvard University Press.
- Henderson, R. (1993). Underinvestment and incompetence as responses to radical innovation: Evidence from photolithographic alignment equipment industry. RAND Journal of Economics, 24:248-270.
- Henderson, R.M. & Clark, K.B. (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. Administrative Science Quarterly, 35: 9-30.
- Levinthal, D.A. & March, J.G. (1993). The myopia of learning. Strategic Management Journal, 14: 95-112.
- Levitt, B. & March, J.G. (1988). Organizational learning. Annual Review of Sociology, 14: 319-340.
- Klepper, S. (1997). Industry life cycles. Industrial and Corporate Change, 6: 145-181.
- Klepper, S. & Simons, K.L. (2000). Dominance by birthright: Entry of prior radio producers and competitive ramifications in the U.S. television receiver industry. Strategic Management Journal, 21: 997-1016.
- March, J.G. (1991). Exploration and exploitation in organizational learning. Organization Science, 2(1): 71-86.
- McKendrick, D.G., Carroll, G.R., Jaffee, J. & Khessina, O.M. (2000). In the bud? Analysis of disk array producers as a (possibly) emergent organizational form. Report 2000-04, Information Storage Industry Center, U.C. San Diego.
- Merrill Lynch & Co. and McKinsey & Company (2001). The Storage Report – Customer Perspectives & Industry Evolution. Special report of a joint industry study.
- Methe, D., Swaminathan, A. & Mitchell, W. (1996). The underemphasized role of established firms as the source of major innovations. Industrial and Corporate Change, 5: 1181-1203.
- Mitchell, W. (1994). The dynamics of evolving markets: The effects of business sales and age on dissolutions and divestitures. Administrative Science Quarterly, 39: 575-602.
- Nelson, R. and Winter, S. (1982). An Evolutionary Theory of Economic Change. Harvard University Press
- Penrose, E. (1958). The Theory of the Growth of the Firm. New York: Wiley.

- Petersen, T. (1991). Time-aggregation bias in continuous-time hazard-rate models. In Masden, P. (ed.) Sociological Methodology, 21: 263-290. Oxford: Basil Blackwell.
- Pfeffer, J. (1981). Power in Organizations. Marshfield, MA: Pitman.
- Pfeffer, J. & Salancik, G.R. (1978). The External Control of Organizations. New York: Harper & Row.
- Podolny, J. & Stuart, T. (1995). A role-based ecology of technological change. American Journal of Sociology, 100: 1224-1260.
- Porter, M.E. (1985). Competitive Advantage. The Free Press, New York.
- Purcell, L. (2000). CD-R/DVD: Disc Recording Demystified. McGraw-Hill.
- Rao, H. (1994). The social construction of reputation: Certification contests, legitimation, and the survival of organizations in the American automobile industry: 1895-1912 Strategic Management Journal, 15:29-44.
- Schoonhoven, C., Eisenhardt, K. & Lyman, K. (1990). Speeding the product to market: Waiting time to first production introduction in new firms. Administrative Science Quarterly
- Sorensen, J.B. (1999). Stpiece: A program for the estimation of piecewise-constant rate hazard models in STATA 6.0. Unpublished ado-file. University of Chicago: Graduate School of Business. Found at <http://gsbwww.uchicago.edu/fac/jesper.sorensen/more/>.
- Sorenson, O. (2000). Letting the market work for you: an evolutionary perspective on product strategy. Strategic Management Journal, 21: 577-592.
- Stinchcombe A.L. (1965). Social structure and organizations. In March, J.G. (ed.) Handbook of Organizations, Chicago: Rand McNally.
- Stuart, T.E., Hoang, H. & Hybels, R.C. (1999). Interorganizational endorsements and the performance of entrepreneurial ventures. Administrative Science Quarterly, 44: 315-349.
- Teece, D.J. (1982). Towards an economic theory of the multiproduct firm. Journal of Economic Behavior and Organization, 3: 39-63.
- Teece, D.J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Research Policy, 15(6): 285-305.
- Teece, D.J. (2000). Managing Intellectual Capital: Organizational, Strategic, and Policy Dimensions. Oxford: Oxford University Press.
- Tripsas, M. (1997). Unraveling the process of creative destruction: Complementary assets and incumbents survival in the typesetter industry. Strategic Management Journal, Summer Special Issue 18: 119-142.
- Tushman, M.L. & Anderson, P.C. (1986). Technological discontinuities and organizational environments. Administrative science Quarterly, 31: 439-465.
- Tushman, M.L. & Rosenkopf, L. (1992). Organizational determinants of technological change: Toward a sociology of technological change, Research In Organizational Behavior, 14: 311-347.