STRATEGIC KNOWLEDGE DISCLOSURE: ITS EFFECT ON COMPETITIVE RESPONSE AND KNOWLEDGE-BASED COMPETENCIES IN THE GLOBAL HARD DISK DRIVE INDUSTRY

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Submitted to the Graduate Faculty of

The Katz Graduate School of Business in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2010

UNIVERSITY OF PITTSBURGH

KATZ GRADUATE SCHOOL OF BUSINESS

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How does a leading firm sustain its competence-based advantage in a competitive landscape against threats of imitation and substitution? In high-velocity competitive markets, an inherent tension arises when firms wish to prolong the value of their technological competencies, while rivals seek to make those competencies obsolete. These markets are characterized by continuous technological change, fickle customers, and frequent shifts in the competitive landscape. Firms must continually update their innovative competencies that are recurrently targets of imitation and substitution, and managers face challenges in discerning the appropriate competencies their firms should commit to and which they should avoid, resulting in the difficulty of setting straightforward strategic goals for the firm. Looking in the hard disk drive industry from 1987 to 1999, I empirically show that leading firms' knowledge disclosure of core technologies has a positive effect on the probability of laggards imitating the leader. Moreover, I show that after leading firms disclose, they introduce next-generation products sooner and prevent laggards from quickly introducing their next-generation products. Thus, I suggest that a leading firm's knowledge disclosing activities can shape the competitive landscape by influencing rivals' scope of search for innovation opportunities. Namely, leading firms can prolong their established competencies by disclosing knowledge on their innovations by promoting imitation and delaying or preventing substitution.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

First, I am grateful to my Lord God for giving me the guidance and perseverance to complete this work. I deeply thank my adviser, Susan K. Cohen, for her wisdom, patience, enthusiasm, and kindness to help me stay focused and push through the challenges of writing my dissertation. She is a dear friend and a wonderful mentor. I extend my gratitude to my dissertation committee: Sharon James, Kevin Kim, Ravi Madhavan, and John Prescott. Each of you generously shared your time and wisdom, and your insights truly helped to develop this study. Moreover, I appreciate the ongoing support from my colleagues in the doctoral program (current and past), including Turanay Caner, Jeung-Yoon Chang, Kevin Cruz, Richard Herko, Sean Tsuhsiang Hsu, Akie Iriyama, Jay Lee, Jason Park, Jackqueline Pike, Wei Lei Shi, Sangyoon Shin, Franky Surpiyadi, Emily Stiehl, Jeremy Suiter, and many others. Doctoral student life would have been dull without you! I deeply thank Carrie Woods, Assistant Director of the Katz Ph.D. program and Gina Cecchetti, Admissions Representative. There was not a day when I did not laugh and smile after talking with you on any occasion. I also thank the numerous supporters at the Korean Central Church of Pittsburgh who spiritually encouraged me through the dissertation process. I am grateful to my parents, Joung-Yong Lee and Jae-Ok You, my parents-in-law Doo-Chae Jung and Bok-Hee Kwon for their never-ending love and support. Finally, I am indebted to my wife Hyunzee Jung, who has been an intellectual colleague, a dedicated mother, and a beloved soul mate. I congratulate her as she has finished her Ph.D. in Social Work at the University of

Pittsburgh. I would not leave out Jimin S. Lee, my beloved daughter, who has endured her first two years in this world with her busy daddy and mommy writing their dissertations.

DEDICATION

I dedicate this dissertation to my Savior and Shepherd Jesus Christ, who died so that I can live.

1.0 INTRODUCTION

1.1 MOTIVATION AND CONTRIBUTION

In any industry, leading firms constantly face competitive threats of imitation and substitution (Barney, 1991; Ghemawat, 1986; Porter, 1985)[1]. However, managing these two threats simultaneously is often a difficult task in high-velocity, technology-intense markets since continuous technological change, fickle customers, and frequent shifts in rivals' imitation and substitution strategies heighten the uncertainty of what technological standard would prevail. Managers of leading firms face challenges in discerning the appropriate competencies their firms should commit to and which they should avoid, resulting in the difficulty of setting straightforward strategic goals for the firm. In these environments profit margins per product generation tend to be small, and there is a constantly increasing demand for new technologies. Thus, leading firms must continually update their competencies and consistently succeed in the race for innovation (Aoki, 1991; Bhattacharya & Ritter, 1983), anticipating and setting the next technological standard (Anderson & Tushman, 1990; Arthur, 1989; Farrell & Saloner, 1985;

[1] My assumption of the conceptualization and operationalization of imitation and substitution is that they are two ends of a continuum at the component level. Namely, a next-generation product that is introduced to a market by a laggard is either imitation or substitution, not both. It either produces a component (or set of components) which is (are) similar (imitate) or different (substitute). In this context, imitation would be different from substitution since the resources and capabilities that are required to carry out the two competitive responses are substantially different (e.g. thin film head technology and ferrite film head technology requires different types of technological knowledge and process knowledge.)

Garud & Kumaraswamy, 1993). At the same time, these firms need to build some elements of stability into their capabilities in order to exploit their established competencies (Benner & Tushman, 2003; Burgelman, 2002; March, 1991). Evidence from prior studies on competition in hypercompetitive settings show that leading firms are easily dethroned or even fail to survive in the market when they are not successful in delicately managing the need to change frequently and yet perform reliably within each technology generation (Christensen, 1997; Christensen & Bower, 1996; Smith et al., 2001; Suarez & Utterback, 1995). For instance, Christensen et al. (1998) showed that in the hard disk drive industry all of 17 firms that had populated the industry in 1976 had not survived until 1990, 100 of 124 firms that had entered the industry during the period had failed and exited, or had been acquired. He argued that firms that had entered emerging (rather than established) markets with architectural (rather than incremental component) innovations had a higher probability of survival, but only when they entered before the establishment of a dominant design.

How can leading firms maintain the stability to exploit established competencies while successfully exploring for innovations? I argue that this question can be answered by examining the competitive dynamics between leaders and laggards in terms of imitation and substitution. Namely, since substitution poses a more formidable threat than imitation, the success of introducing next-generation innovations and setting the dominant design depends on how the leading firms manage the threat of substitution in conjunction with imitation. More specifically, drawing from an attention-based view of the firm (Ocasio, 1997), I suggest that the disclosure of leaders' knowledge on its innovative efforts promotes imitation and therefore delays potential substitution, rendering the stability to prolong the technological playing field. At the same time, leaders may gain the flexibility to achieve speed in developing next-generation technologies that set dominant designs.

In pursuing this issue, I claim to make three contributions to the literature of innovation and competitive dynamics. First, I take into consideration both imitation and substitution as competitive threats and show how leading firms may deal with them simultaneously but differently. Firms would reap enduring value from resources and capabilities if they withstand both imitation and substitution, rather than focusing solely on protecting imitation barriers (Adner & Zemsky, 2006; Chen, 1996; Dierickx & Cool, 1989; McEvily et al., 2000; Peteraf & Bergen, 2003). Interestingly, while the resource-based view (Barney, 1991; Peteraf, 1993; Rumelt, 1984; Wernerfelt, 1984) has defined the resources that renders a firm its sustaining competitive advantages as valuable, rare, inimitable, and non-substitutable (Barney, 1991), we find a lack of focus considering how firms protect their technological competencies against imitation *and* substitution (Adner & Zemsky, 2006). Thus, while resource-based view scholars acknowledge the issue of resource value and substitution, the construct is less developed than that of barriers to imitation (Adner & Zemsky, 2006; Priem & Butler, 2001).

Prior studies have even emphasized the relatively higher importance of dealing with substitution compared to imitation, arguing that substitution may be more formidable in the sense that it has a higher probability to displace a firm out of the competitive landscape (Golder & Tellis, 1993; Ma & Karri, 2005; Yoo, 2005). For example, Janney and Dess (2006) contended that while the threats of imitation will erode a firm's returns to a breakeven level, the threats from substitution can make a rival firm's resource obsolete, rendering them without any value. Thus, I examine how leading firms may even promote imitation to some extent in order to delay or prevent substitution by laggards.

Second, I build on the literature of voluntary knowledge disclosure, and assert that leading firms may have strategic motivations to disclose knowledge to their rivals. The conventional wisdom on disclosure is that managers would guard information through various mechanisms (e.g. secrecy or developing complex, specific and tacit resources) since knowledge appropriation prevents rivals from knowing what to imitate or how to develop substitutes for its capabilities (Barney, 1991). Further, secrecy would give leading firms the time to establish dominant positions and appropriate returns from an innovation, while staying ahead of rivals (Cohen et al., 2000; McEvily & Chakravarthy, 2002). If a firm does voluntarily disclose knowledge (e.g. information on R&D projects, technologies from launched products, information in patents, etc.), it faces a dilemma that is called the "paradox of disclosure (Arrow, 1962)." This has been observed in situations to reduce information asymmetry, such as when a firm discloses information to its current or potential investors. Namely, disclosure reduces uncertainty and helps investors make better estimates of R&D outcomes and future profits, thus reducing financing costs for the disclosing firm (James, 2007). The paradox is that the disclosing firm becomes more transparent and is left more susceptible to imitation risk by its competitors. In other words, disclosure may attract rivals' attention and spur efforts to erode imitation barriers, and as a result, competitors may benefit from lower innovation costs or time-to-discovery, challenging the survival of the leading firm (Bhattacharya & Ritter, 1983; Choi, 1991). Thus, firms would disclose only if the expected benefits of disclosure exceed the perceived proprietary costs of disclosure. While studies have considered the positive effects of knowledge disclosure, such as a firm's stock price (Botosan, 1997; Botosan & Plumlee, 2002) or increased opportunities of access to external financing, it is less clear in a competitive dynamics sense why firms would disclose knowledge and how it affects the competitive landscape.

Recently, some studies have focused on the strategic motivations to disclose knowledge. James (2007) showed that when firms have technological capabilities that reduce imitation risk, they would have strategic incentives to disclose even in the absence of financing incentives, for example, benefiting from broadcasting their capabilities to attract potential marketing collaborators or licensees of a given technology. Other studies such as Coff, Coff, & Eastvold (2006), Coff, Lee & Hayward (2008), and Harhoff (1996) suggest that firms may increase their ability to exploit their competitive advantages by voluntarily disclosing information on their R&D efforts. These studies typically assume that imitation barriers, either from "no disclosure" or "disclosure and fending off imitators," is the main source of sustaining its competitive advantage. However, in some industries such as the hard disk drive industry, leading firms vigorously engage in knowledge disclosure activities (e.g. patent application[2], publications, joint research consortiums, announcements through media, strategic alliances) even when the rate of imitation is high (Mansfield, 1961, 1984; Mansfield et al., 1981). Interestingly, the hard disk drive industry is not an environment that provides strong patent protection, and the firms that are disclosing knowledge in the industry are not always those with strong technological capabilities. Regarding the arguments that firms that operate in industries with weak patent protection have greater imitation risk and consequently are more likely to face greater competition and lower profits after an increase in disclosure (James, 2007), I argue that knowledge disclosure by leading firms before a dominant design is established in product architecture has strategic implications. Responding to James and Shaver's (2008) call that "we know of no empirical

[2] Although patents are commonly understood as a means to appropriate and protect a firm's knowledge, patent grants have been shown to have a disclosure effect with various motivations (Lhuillery, 2006). Moreover, patent counts have been used as a proxy of knowledge disclosure, especially with respect to the technological component of a firm's product, in various studies (Baker & Mezzetti, 2005; Coff et al., 2008; De Fraja, 1993; Lichtman et al., 2000).

studies that test the effect of disclosure on rivals," I propose and test the strategic motivations of firms' knowledge disclosure and the effects of knowledge disclosure on competitive reactions in the context of innovation and technological development.

Third, I bridge competitive dynamics (Chen, 1996; Chen et al., 1992; Ferrier et al., 1999; Grimm & Smith, 1997; Smith et al., 1992) and the attention-based view of the firm (Ocasio, 1997), suggesting in order to exploit their technological competencies and explore for innovations, leading firms may disclose knowledge so as to influence laggards' scope of search. Literature on how firms' deploy innovative efforts has mainly focused on the focal firm's internal capabilities rather than in conjunction with rivals' competitive actions. For example, proponents of the resource-based view (Barney, 1991; Dierickx & Cool, 1989; Rumelt, 1984; Wernerfelt, 1984) and the knowledge-based view (Kogut & Zander, 1992; Spender & Grant, 1996) have mainly focused on the resources that have isolating mechanisms such as causal ambiguity, firm specificity, or social complexity, assuming that these resources would assure the difficulty for rivals to imitate (Coff et al., 2008). However, such resources are not entirely inimitable since rivals may develop their own substitutes (Adner & Zemsky, 2006; Coff et al., 2008; Makadok, 2001). A competitive dynamics view, examining the interaction between the firm and its competitive environment, would give us a clearer picture on how leading firms manage their knowledge-based competencies when they are confronted with threats of imitation and substitution.

While competitors are constantly searching for new innovations (Katila & Ahuja, 2002; Nelson & Winter, 1982), it is oftentimes local or familiar territory where managers of rival firms search for directions of innovation since they are boundedly rational (Cyert & March, 1963). Due to information asymmetry between leaders and laggards, leaders are constantly threatened by the uncertainty of various potential substitutes, since each laggard may pursue their own way of solutions to innovate. Namely, the imperfect nature of information influences what strategies are undertaken in response (Chen, 1996). As a mechanism of signaling and gaining attention, knowledge disclosure may reduce information asymmetries, increasing the familiarity of the leaders' innovation (Ocasio, 1997) and thus promoting laggards to imitate. Consequently, leaders can delay or prevent substitution and may enjoy lead time in innovating next-generation technologies. Thus, I build on the competitive dynamics literature and the attention-based view by considering how leaders might influence laggards' attention of search processes for innovation.

In sum, I propose a strategic motivation of knowledge disclosure and empirically test the effect of leading firms' knowledge disclosure on the competitive behavior of rivals (i.e. imitation and substitution), and test the sustainability of the technological competence of the knowledge-disclosing firm, after the disclosure has been made.

1.2 RESEARCH SETTING: THE HARD DISK DRIVE (HDD) INDUSTRY

The Hard Disk Drive (HDD) industry has been characterized as a competition amongst HDD manufacturers in a high-paced, high-stakes race for leadership in both technology and the cost of production. To survive in the industry, HDD firms have been under time pressure to introduce higher storage capacities on ever-smaller devices at less cost and in less time (McKendrick et al., 2000).

1.2.1 Technological Challenge

Technological development in the hard disk drive industry has been made along two main dimensions –capacity and size. The technological challenge for hard disk drive firms is to deliver drives with higher capacity in terms of the number of bits of data that can be stored on every square inch of the disk, otherwise known as the HDD's areal density (AD). Since IBM shipped the first movable-head disk drive in 1956, the industry has undergone tremendous technological change. Until 1991, areal density increased at an annual rate of 30 percent, but grew by an astounding 60 percent per year from 1992-1997, a faster rate of progress than semiconductors, and an amazing 125 percent in 1998, our last year of study. Even with industry age, technological change in this industry has been accelerating. Figure 1 shows the growth in areal density for four different form factors.

Insert Figure 1 about here

This explosion of areal density development pressed firms to be first to the market with a new drive with higher capacity, and those that were late to market typically suffered a severe revenue penalty, having forced either to absorb their R&D costs and start with the next generation capacity drives or to exit the industry (McKendrick, 2004). First mover leadership in terms of innovation typically was not sustained, and the rapidly decreasing profitability within each product life-cycle pushed firms to innovate as quickly as possible. Many firms could not keep up with the continuous demand of new product innovations, and as a result had exited the industry (Figure 2).

Insert Figure 2 about here

Along with capacity enhancements, HDD firms have been faced with demand of reducing the physical size of disk drives, called "form factors." Form factors have been shrinking from disk diameters of 39, 31 and 24 inches to 14, 8, 5.25, 3.5, 2.5, 1.8, 1 and 0.85 inch drives.[3] These changes in size were problematic for many drive manufacturers, and most firms did not survive the transitions. For some HDD firms, technological factors lay behind the inability to introduce smaller form factors: scaling down components, or substituting more advanced ones, and getting designs to work properly constituted non-trivial engineering challenges (McKendrick, 2004). Other firms had failed to build smaller form factors and serve customers in new markets (Christensen, 1997). Following is a summary of the various form factors and the firms that first used the form factors.[4]

14 inch drives

In 1973, IBM introduced the first "Winchester" drive, a permanently sealed drive that kept the disks, heads, motors, actuators and electronics inside a dust-proof housing. This architectural innovation overcame the inherent limit of the recording density – proximity of the heads positioned to the disks and particulate contamination on the disk surfaces causing read/write errors. Figure 3 shows the primary components of the Winchester drive.

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[3] Although there were larger drives in earlier years, the 14-inch drives were the first that were "Winchester drives," sealed drives that served as the standard worldwide. A more detailed description of earlier, larger drives can be found in Christensen (1993).
[4] Excerpt form Christensen (1992) and www.wikipedia.com

Insert Figure 3 about here
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8 inch drives

In 1979, Shugart Associates' SA1000 was the first form factor compatible HDD, having the same dimensions and a compatible interface to the 8 inch floppy disk drive.

5.25 inch drives

This smaller form factor, first used in an HDD by Seagate in 1980, was the same size as full height 5¼-inch diameter floppy disk drive, i.e., 3.25 inches high. This is twice as high as "half height" commonly used today; i.e., 1.63 in (41.4 mm). Most desktop models of drives for optical 120 mm disks (DVD, CD) use the half height 5¼ inch dimension, but it fell out of fashion for HDDs.

3.5 inch drives

This smaller form factor, first used in an HDD by Rodime in 1983, was the same size as the "half height" 3½ inch floppy disk drives. Today it has been largely superseded by 1-inch high “slimline” or “low-profile” versions of this form factor which is used by most desktop HDDs.

2.5 inch drives

This form factor was introduced to the industry by PrairieTek in 1988. It has been widely used for hard-disk drives in mobile devices (laptops, music players, etc.) and as of 2008 replacing 3.5

inch enterprise-class drives. It is also used in the Xbox 360 and Playstation 3 video game consoles.

1.8 inch drives

This form factor, was introduced by Integral Peripherals in 1993. It is increasingly used in digital audio players and subnotebooks. These became popular for their use in iPods and other HDD based MP3 players.

1 inch drives

This form factor was introduced in 1999 as IBM's Microdrive to fit inside a CF Type II slot. Samsung calls the same form factor "1.3 inch" drive in its product literature. Toshiba announced this form factor in January 2004 for use in mobile phones and similar applications, including SD/MMC slot compatible HDDs optimized for video storage on 4G handsets.

1.2.2 The Emergence of HDD Markets

The PCM market

The emergence of the independent hard disk drive industry can be traced to the early 1960s, as companies were founded to manufacture disk drives that were plug-compatible with IBM equipment. This market was called the PCM Market, and until the mid 1970s, this market was the largest outlet for non-vertically integrated, independent disk drive firms (Christensen, 1992). Some of the early pioneering firms of the PCM market were Telex Corp., Storage Technology Corp. (STC), Control Data Corp. (CDC), Century Data, International Storage Systems (ISS), Pertec, Wangco and Kennedy. These firms sold disk drives directly to users of IBM computers who were in need of data storage. They were product imitators rather than innovators, offering cheaper products than IBM. For example, IBM's model 1311 price was $26,000 in 1962, compared with the compatible drives of other rivals between $8,000 to $12,000 (Christensen, 1992). The PCM market had reached its peak at $700 million in sales in 1985, from $100 million in 1970. Table 1 shows the major players and its annual sales in the PCM market between 1976 and 1986.

Insert Table 1 about here

The OEM market

The OEM market emerged with the explosive growth of the minicomputer industry in the 1970s. While larger computer manufacturers such as IBM, DEC, Control Data, Data General, Burroughs, HP and Univac made most of their own drives, non-integrated firms such as Wang, Prime, NCR and Nixdorf in the 1970s and Apple, Commodore, Compaq, Tandy, and Sun Microsystems in the 1980s blossomed the OEM market for independent disk drive manufacturers. The OEM market grew about 25% annually between 1976 and 1998, attracting over 100 entrants worldwide. Christensen (1992) categorized the OEM firms into five groups: *De novo* start-up firms, related-technology firms, related-market firms, forward integrators, and vertically integrated manufacturers.

De novo start-up firms

These firms, mostly venture-capital backed, were founded to design and manufacture Winchester-technology drives, and which remained focused almost exclusively on the disk drive business. By 1973, all of the early firms had been acquired by larger, diversified firms. The majority of these firms entered after 1978.

Related-technology firms

These firms such as Storage Technology and Ampex, entered the market with experience in data recording technologies in other product markets.

Related-market firms

These firms such as Memorex, Diablo, Perkin Elmer and Calcomp were diversified firms that had several product lines made for the computer industry. While related-technology firms had previous experience in related technological fields, these firms had expanded their businesses in terms of related customers.

Forward integrators

These firms started by manufacturing major disk drive components such as read-write heads, which then integrated forward to the design and assembly of complete disk drives.

Vertically integrated manufacturers

These firms historically manufactured a large proportion of the world's hard disk drives. Some, such as DEC and Data General only manufactured for internal, captive consumption. Other firms such as Control Data, Fujitsu and Hitachi competed actively in the OEM market, in addition to supplying their captive needs. IBM and Hewlett Packard began selling drives into the OEM markets in 1984 and 1985, respectively.

The pioneers of the hard disk drive industry were not venture capital-backed firms, rather they were larger firms entering via technological or market relatedness, or by vertical integration. The related-market firms were the largest group until the early 1980s. The related-technology firms came into prominence by the mid 1980s, primarily driven by Seagate. The vertically integrated firms accounted for almost half of the market between 1976 and 1982. The de novo start-ups became leaders from the late 1980s. Table 2 shows the top ten firms ranked by market share.

Insert Table 2 about here

1.2.3 Firm Capabilities to Improve Technical Performance

In the hard disk drive industry, vertically integrated, established firms took the lead in developing and introducing new component technology. One of the main reasons for this is that the development of the new component technologies was often expensive, time-consuming, and uncertain, requiring a vertically integrated R&D process. This process required a full range from basic scientific research, engineering, system design, product design, and process development.

Christensen (1992) gives us a good illustration of the holistic development process of the thin film disk technology:

"From the earliest IBM disk drives, information was stored on the disk surface in microscopic particles of magnetizable iron oxide - the same technological approach employed in predecessor tape recording technologies. Efforts to improve the amount of information which could be stored within a given area of disk surface focused on making the iron oxide particles uniformly smaller; in dispersing and depositing them on the surface as uniformly as possible; and in orienting the particles, which tended to be needle-like in shape, vertically rather than horizontally on the surface to achieve greater particle density.

In the 1970s some manufacturers sensed they were approaching the limits of recording density in particulate iron oxide, and began researching the use of thin film metal coatings as a way to further improve recording density. Thin-film process technology was already highly developed in the integrated circuit industry, but its application to magnetic disks presented substantial challenges. Applying uniform coatings on 8- and 14-inch disks, which were far larger than the silicon wafers used in the IC industry was an initial challenge, but making the relatively soft metal coatings as durable under head crash conditions as the much harder oxide coatings proved exceptionally difficult. Industry participants interviewed for this study estimate that development of thin film disk technology required approximately eight years; an industry total of over $1 billion spent in technology development; and a minimum expenditure of $50 million per firm to develop the product technology, and bring a reliable process to pilot scale."

Development of the thin film head was as much an arduous process, as Christensen (1992) illustrates:

"The original recording head design, called ferrite heads, consisted of small coils of wire wound around gapped ferrite (iron oxide) cores - which essentially was an electromagnet. A primary factor limiting recording density was the size and precision of these electromagnets on the recording head. Ferrite heads had to be ground mechanically to achieve desired tolerances, and by 1981 many felt the limits of precision for making ferrite heads had been reached.

As early as 1965, researchers posited that by sputtering thin films of metal on the recording head and then using photolithography to etch electromagnets on the head's surface, smaller and more precise electromagnets would result, enabling more precise orientation of smaller magnetic domains on the disk surface. Again, although thin film photolithography was well-established in the semiconductor industry, its application to recording heads proved extraordinarily difficult. Read-write heads required much thicker films than did integrated circuits, and the surfaces to be coated were often at different levels, and could be inclined."

Generally, component development proceeded in four stages. First, large firms such as IBM would work to expand its understanding of basic scientific issues such as the physics of magnetic recording and the properties of new materials. The second phase would be stimulated by proof of concept at the large firm such as IBM, and by the leakage of that information to other firms. This led to a broader group of vertically integrated manufacturers - Burroughs, Control Data, Digital Equipment, Fujitsu, Hewlett Packard, Hitachi and NEC - to initiate their own development efforts. The third phase is refinement of product design, establishment of manufacturing process, and incorporation into a new disk drive model. The fourth phase is characterized by the imitation of non-integrated disk drive manufacturers, incorporating the newly developed components into their products.

1.2.4 Component Technology

Because product life cycles have been relatively short and profitability within each life cycle has been decreasing, HDD firms were motivated to innovate quickly and focus on a novel combination of component technologies and design choices, rather than radical innovations which establish new s-curves for technological progress. Thus, setting standards at the component level is one thing they can potentially control and use a route to competitive advantage.

Two main components that the HDD firms had focused on development were the hard disk platters and the read/write heads. In disk manufacturing, a thin coating is deposited on both sides of the platters, and the coating has a complex layered structure consisting of various metallic alloys. Extreme smoothness, durability, and perfection of finish are required properties of a hard disk platter to optimize the data storage process. Throughout the years, platters coated with thin metal films substituted for disks coated with particles of iron oxide.

As for read/write heads, a major shift in the architectural technology of the head occurred in the late 1960s and early 1970s. Namely, heads made through photolithographic processes substituted for heads made by winding copper wire around a machined ferrite core. IBM was the first to explore the use of thin-film technology in 1965, with the foresight that copper wire technology would face a limitation in terms of grinding the ferrite to finer dimensions. Control

Data and Burroughs followed IBM by launching thin-film head development projects, and Burroughs announced a thin-film head model in 1976, although it never went into production. In 1979, IBM introduced its Model 3340 with thin-film heads. By 1999, 19 of 20 firms had incorporated thin-film heads in their products. Table 3 shows the numbers of firms introducing models equipped with thin-film heads from 1987 to 1999.

Insert Table 3 about here

Meanwhile, there was another substitute technology to the copper wire technology, called the metal in the gap (MIG). This technology gave improvement to the ferrite head by placing metal in the gap between the two ferrite block's on the head surface. Although the MIG technology yielded almost equivalent performance to the thin film, the industry had eventually moved to the thin-film technology by the late 1980s. Figure 4 shows metal-coated disks for particulate oxide-coated disks, and Figure 5 shows the substitution of innovative head technology for conventional ferrite head technology.

Insert Figure 4 about here

Insert Figure 5 about here

Switching from the copper wire technology to the thin-film technology was not an easy task for following firms, since the change required other technologies. For instance, according to Christensen (1992), the development of barium-doped ferrite greatly increased the physical strength of the material, permitting the heads to be ground to much finer, more precise dimensions without chipping or cracking. The development of lapping processes permitted manufacturers to grind the ferrite cores even more finely. These new technologies required fundamentally different sets of resources and capabilities, including different sets of engineering competencies, manufacturing equipment, manufacturing flow systems. Following is the time frame of key technology and market events[5].

- First Hard Disk (1956): IBM's RAMAC is introduced. It has a capacity of about 5 MB, stored on 50 24" disks. Its areal density is a mere 2,000 bits per square inch and its data throughput 8,800 bits/s.
- First Air Bearing Heads (1962): IBM's model 1301 lowers the flying height of the heads to 250 microinches. It has a 28 MB capacity on half as many heads as the original RAMAC, and increases both areal density and throughput by about 1000%.
- First Removable Disk Drive (1965): IBM's model 2310 is the first disk drive with a removable disk pack. While many PC users think of removable hard disks as being a modern invention, in fact they were very popular in the 1960s and 1970s.
- First Ferrite Heads (1966): IBM's model 2314 is the first hard disk to use ferrite core heads, the first type later used on PC hard disks.

[5] Excerpt from http://www.storagereview.com/guide/histFirsts.html

- First Modern Hard Disk Design (1973): IBM's model 3340, nicknamed the "Winchester", is introduced. With a capacity of 60 MB it introduces several key technologies that lead to it being considered by many the ancestor of the modern disk drive.
- First Thin Film Heads (1979): IBM's model 3370 is the first with thin film heads, which would for many years be the standard in the PC industry.
- First Eight-Inch Form Factor Disk (1979): IBM's model 3310 is the first disk drive with 8" platters, greatly reduced in size from the 14" that had been the standard for over a decade.
- First 5.25" Form Factor Disk (1980): Seagate's ST-506 is the first drive in the 5.25" form factor, used in the earliest PCs.
- First 3.5" Form Factor Disk Drive (1983): Rodime introduces the RO352, the first disk drive to use the 3.5" form factor, which became one of the most important industry standards.
- First Expansion Card Disk Drive (1985): Quantum introduces the Hardcard, a 10.5 MB hard disk mounted on an ISA expansion card for PCs that were originally built without a hard disk. This product put Quantum "on the map" so to speak.
- First Voice Coil Actuator 3.5" Drive (1986): Conner Peripherals introduces the CP340, the first disk drive to use a voice coil actuator.
- First "Low-Profile" 3.5" Disk Drive (1988): Conner Peripherals introduces the CP3022, which was the first 3.5" drive to use the reduced 1" height now called "low profile" and the standard for modern 3.5" drives.
- First 2.5" Form Factor Disk Drive (1988): PrairieTek introduces a drive using 2.5" platters. This size would later become a standard for portable computing.

- First Drive to use Magnetoresistive Heads and PRML Data Decoding (1990): IBM's model 681 (Redwing), an 857 MB drive, is the first to use MR heads and PRML.
- First Thin Film Disks (1991): IBM's "Pacifica" mainframe drive is the first to replace oxide media with thin film media on the platter surface.
- First 1.8" Form Factor Disk Drive (1991): Integral Peripherals' 1820 is the first hard disk with 1.8" platters, later used for PC-Card disk drives.
- First 1.3" Form Factor Disk Drive (1992): Hewlett Packard's C3013A is the first 1.3" drive.

The HDD industry is a good setting to examine how firms faced with swift-paced technological demands manage their product innovation activities. Especially, this context is ideal in looking at how firms deal with competitive threats by influencing competitors' R&D efforts of when to invest in certain component technologies that might shape the technology frontiers of the industry.

1.3 LITERATURE REVIEW

This section briefly reviews literature on knowledge disclosure and competitive threats that provides the foundation for this dissertation. I later develop arguments to explain why and how leading firms in the hard disk drive industry disclose knowledge in order to prolong their knowledge-based competencies by promoting imitation and delaying substitution.

1.3.1 Motivation of Knowledge Disclosure

A firm's knowledge disclosure activity ranges from no disclosure to full disclosure, depending on the firm's motivations (James, 2007). Following is a review of extant literature on the motivations of knowledge disclosure. Although prior research provides useful theoretical underpinnings, it does not adequately explain the influence of a firm's knowledge disclosure on its rival's competitive strategy in terms of imitation and substitution, and also how firms may utilize knowledge disclosure as a mechanism to prolong their knowledge-based competencies. Two streams have mainly considered the motivations of knowledge disclosure - the finance and accounting literature, and the innovation literature.

1.3.2 Finance and Accounting Literature

Capital market transaction theory argues information asymmetry impedes the efficient allocation of resources in a capital market economy, and disclosure by firms geared towards investors play an important role in mitigating these problems (Healy & Palepu, 2001). Due to information differences and conflicting incentives, investors might undervalue "good" projects and overvalue "bad" projects, leading to the inefficiency in capital markets and potential market breakdowns (Akerlof, 1970; Healy & Palepu, 2001). Also, firms will view making public equity or debt offers to be costly for existing shareholders. Thus, firms have incentives to disclose knowledge by themselves or by intermediary institutions in order to mitigate the information asymmetry and optimize any contracting between the firms and their investors or their creditors and reduce the firm's cost of external financing (Christie & Zimmerman, 1994; Holthausen & Leftwich, 1983; Watts & Zimmerman, 1990).

In a competition viewpoint, theoretical models in corporate finance and accounting suggest that firms are reluctant to disclose information that consequently leads to the increase of imitation risk (James, 2007; Yosha, 1995). Namely, firms will disclose knowledge to reduce financing costs only when the expected positive effect of disclosure on market value is higher than the strategic costs, such as reduction in present value of future cash flows as a consequence of imitation (Healy & Palepu, 2001; Verrecchia, 2001). However, prior studies show that firms have other strategic motivations beyond lowering financing costs. As James (2007) suggests, the theories lack empirical support of the influence of financing versus strategic concerns on the decision to disclose knowledge. A strategic view of knowledge disclosure has been considered more extensively in the innovation literature, as explained in the following section.

1.3.3 Innovation Literature

The basic assumption with respect to knowledge disclosure in the innovation literature, as with the finance and accounting literature, is that firms face trade-offs when disclosing strategic information. Namely, firms that voluntarily disclose information about R&D projects, in order to reduce any information asymmetry between its investors and consequently achieve lower financing costs, face the risk of increased competition by rivals that utilize the disclosed information to improve their R&D efforts. Due to disclosure and subsequent spillovers, rivals may imitate or make a discovery with no extra cost (De Fraja, 1993). Moreover, knowledge disclosures may act as signals of opportunity, inviting other competitors to continue R&D

projects when they might have otherwise dropped out of the race (Aoki, 1991; Lippman & McCardle, 1987). As a consequence, firms that disclose knowledge may lose their profits from their innovations. Thus, firms will weigh the benefits of disclosure against the potential costs (Choi, 1991; De Fraja, 1993) and will disclose knowledge to a greater degree only when the benefits exceed the costs (Bhattacharya & Ritter, 1983). Beyond the motivation to lower financing costs, scholars examining firms' innovative efforts have examined the strategic motivations behind knowledge disclosure.

For example, Coff, Lee, & Hayward (2008) suggested that firms may disclose information about technological breakthroughs either when they need complementary resources, when they need to garner attention in order to fully exploit the advantage, or when there is managerial opportunism whereby managers stand to gain personally by controlling the timing of key information releases. The first motivation depicts the need for smaller firms to disclose when they have new technologies but do not necessarily possess the resources to carry out the later stages of development or marketing. The second motivation depicts knowledge disclosure when firms either seek to exploit market opportunities, technology market opportunities, or private knowledge trading with alliance partners. The third motivation depicts an agency problem where managers may disclose information to profit personally through insider trading. Harhoff (1996) and Harhoff et al. (2003) also argued that firms may increase the appropriable value of R&D investments by disclosing technologies to potential licensing partners. Also, Tripsas (1997) contended that by disclosing knowledge, firms may gain partnerships with other firms that possess resources and capabilities that enable the commercialization of an innovation, including complementary manufacturing and marketing capabilities.

With respect to disclosure targeted to rivals, Penin (2007) suggested several motivations: to nurture an environment of openness, to implement the innovation as a standard, to prevent other firms from patenting the disclosed innovation, and to trigger reputation effects.[6] Based on game theoretical logic, nurturing an environment of openness refers to the reciprocal pattern of knowledge disclosure among rivals when one firm is not capable of solving all technological problems. Here, knowledge disclosure is acknowledged as a tacit agreement, where the creation of an environment of openness and implicit collaboration is rendered possible mostly by repetition of interactions (Von Hippel, 1987). Implementing the innovation as a standard refers to firms disclosing partially to decrease the cost for rivals to adopt the innovation of the disclosing firm. Preventing rivals from patenting refers to knowledge disclosure mostly aimed at the prevention of rivals patenting the innovation while saving patent application costs. Failure to disclose knowledge increases the risk of being excluded from the industry by a rival patent (Cohen et al., 2000). Triggering reputation effects refers to firms gaining benefits from knowledge disclosure, increased demand due to the reputation of a firm disclosing its innovativeness, deterring potential rivals from entering their market niches, gaining easier access to financial markets and public funding, and facilitating R&D cooperation with potential partners by signaling its competencies.

Meanwhile, prior studies have suggested that there are contingencies to the determinants of knowledge disclosure. For example, firms that possess superior resources and capabilities that are necessary to develop and commercialize an innovation may lower imitation risk since rivals may find it difficult to imitate and reap profit from their innovative ideas (Teece, 1986). Competitors that possess relatively inferior resources and capabilities are likely to have lower

[6] Penin (2007) has also introduced other motivations of knowledge disclosure towards suppliers and customers, but I focus on knowledge disclosure towards rivals in this study.

absorptive capacity (Cohen & Levinthal, 1989, 1990) to absorb and process the disclosed knowledge and therefore may not become as effective as the leaders in the competition. Mansfield et al. (1981) showed that innovations were imitated at roughly 65 percent of the innovator's costs except when firms possessed superior technical and other capabilities necessary to commercialize the innovation. In terms of imitation risk and the propensity to disclose knowledge, James (2007) and James & Shaver (2008) showed that technological interdependencies and a firm's stock of essential technologies have a positive effect on a firm's subsequent knowledge disclosure. In addition, they show that firms in an industry with stronger patent protection will disclose more knowledge than firms in an industry with weaker patent protection. For interdependencies, they argued that firms with R&D projects that draw on interdependent technologies would disclose more since they face lower potential competition, due to the fact that imitators lack internal technical skills that are necessary to develop competing products. For a firm's stock of essential technologies, they argued that firms that own critical technologies would disclose more since they have the capability to achieve expected profits faster than potential rivals. For the strength of patent protection differences, they argued that firms operating in strong patent protection industries would disclose more since they would be less concerned of profitability reduction due to imitation. Namely, there would be higher imitation costs due to stronger legal remedies for the disclosing firm.

In sum, firms disclose knowledge when there is low imitation risk or when there are potentially greater benefits of knowledge disclosure when compared to the risk of imitation of rivals. While firms may have strategic motivations and benefits of knowledge disclosure, prior studies are silent on how rivals react to a firm's strategic knowledge disclosure and how knowledge disclosure may affect the sustainability of a firm's competence. Namely, it is unclear on how knowledge disclosure affects the risk of substitution by rivals compared to the risk of imitation. The next section develops a theory that explains why and how firms might promote imitation, rather than avoiding it, in order to prevent substitution and prolong their technological playing field.

2.0 THEORY AND HYPOTHESES

While leading firms in high-velocity markets, such as the hard disk drive industry, are pressured to search for new innovation opportunities, they are also trying to exploit their established technological competencies. However, they are not alone in the innovation race. Competing incumbents and new entrants constantly search for innovations that might erode the leader's imitation barriers or disrupt the market, threatening their enthronement and even their very existence. The question for the leading firm is how to effectively address the two forms of competition. In this section I develop my hypotheses by explaining the motivations of knowledge disclosure by the leaders, the motivations of imitation by the laggards when knowledge is disclosed, and how the leaders may succeed in prolonging their current technological playing field while winning the innovation race and setting the standard by introducing next-generation products quicker.

2.1 WHY AND HOW LEADERS WOULD DISCLOSE KNOWLEDGE

As aforementioned in the introduction section, leading firms that are successful in technology-intense industries balance the need to change frequently yet perform reliably within each product generation, while addressing threats of imitation and substitution. In this section, I explain the conditions that would motivate leading firms to disclose knowledge in order to promote imitation while delaying or preventing substitution.

First, in high-velocity and technology-intense markets, there is a need for leading firms to develop and introduce next-generation innovations that would establish the technological standards. As expressed as the “battle for technological dominance against other technological designs (Suarez, 2004),” in these environments, technological standards are constantly changing, and there is a high level of uncertainty of what would be accepted as the next-generation innovations (Adner & Zemsky, 2006; D'Aveni, 1994; Eisenhardt, 1989). Although they need not be superior in terms of performance (Adner, 2002; Christensen, 1997), the next-generation innovations may easily and unexpectedly disrupt the markets and displace the leading firms that lag behind in the innovation race, mostly due to organizational inertia (Hannan & Freeman, 1984; Kelly & Amburgey, 1991; Miller & Chen, 1994). Thus, an imperative motivation for the leading firm is to gain dominance in technological designs by quickly introducing next-generation innovative products.

Second, before technology standards are set, there is a need to prolong the leaders’ technological playing field in order to exploit their established knowledge-based competencies. While this prolonging is achieved through technology dominance of the leaders, the notion of dominance is related to studies on the sociology of science and technology (Suarez, 2004). Sociological perspectives argue that contacts will drive the criteria that inventors use to evaluate new approaches, compare their performance potential, and hence will heavily influence their perceptions of which offers the greatest opportunities (Greve, 1996; Greve & Taylor, 2000; Haunschild, 1993; Haunschild & Beckman, 1998). Leaders may want to affect the emergence of a dominant design (or standardization of design) in the market by influencing the attention

(Ocasio, 1997) of laggards of where to search and what to search for with respect to innovation opportunities. By doing this, they may also encourage investment into complementary products and industry infrastructure, promoting investments which are necessary for production economies of scale (Spencer, 2003; Utterback & Suaraz, 1993). Also, Spencer (2003) argued that by influencing the priorities of players, the firm can persuade innovators along all technological trajectories to compete on the firm's own terms. She argued that an institutional environment sets the framework for market transactions and provides important resources for economic actors, legitimizing organizational forms and technologies. According to institutional theorists, agents play a critical role in shaping the forces of institutions and laying out normative standards in an industry (DiMaggio & Powell, 1983 [1991]; Selznick, 1957, 1996). In emerging high-technology industries, a core component of the institutional environment is the technological standard of a product's development, and the technological advances of firms co-evolve with the institutional environment (Spencer, 2003). Namely, when laggards imitate the leading firms by disclosing knowledge, the leaders can increase their legitimacy by shaping the institutional environment in favor of their own technology.

Interviews with managers of leading hard disk drive firms show that it is common for firms to let new technological ideas float around, creating a "buzz" amongst the technology communities to promote the validity of their innovations. When the next-generation of dominant designs are not solidified, firms encourage various players, including their rivals, to adopt and imitate their technologies. A former Seagate engineer said:

> "If you try to innovate entirely on your own, you run a very high risk of having other companies choose another path. You want your technology accepted before your

competitors get there (achieve similar performance measures) via other paths (substitution), in which case R&D dollars you have invested in your own approach could become wasted."

A Seagate technology manager also mentioned:

"If you go down one path (of technology development) and commit to it, you are spending hundreds of millions of dollars going down that path. It's a big bet (and high risk) if you are on your own. You're reducing some risk by letting some information out in the public domain. You'll get feedback because people will talk to you. And frequently they'll come up with solutions your own team hasn't thought of yet….You want to be aware of what is being discussed. Eventually, they (the community including rivals) will accept and use your technology."

Namely, leading firms want to persuade their communities (those including competing rivals and potential new entrants) the legitimacy of their technologies against competing ones by encouraging rivals to incorporate the technologies into their products. One might view this promotion of imitations as a means to delay or prevent substitution. This makes sense for leading firms since they are making huge investments in their technologies and would not want to see them knocked off the market.

Leading firms may disclose knowledge to promote imitation when they are searching for new markets. For example, Memorex, a leader in 14-inch disk drives took an "open technology" policy, disclosing the electronic and mechanical specifications publicly available and freely usable by its competitors. Seagate also followed the business model of standardized open technology, in order to promote their technology in their hard drives so as to establish new markets for unproven technologies (Hughes, 2006). Ironically, Seagate had suffered in competition in later years during the transition from the perpendicular recording[7] to potential future technologies for not disclosing their research on Heat Assisted Magnetic Recording (HAMR), while competitors would introduce other technologies and capture markets. According to a former Seagate technology manager:

> "There are three competing technologies that would be the next generation moving from perpendicular recording in the heads (Heat Assisted Magnetic Recording, Bit-Patterned Media Recording and Two-Dimensional Magnetic Recording), particularly for hard drives that goes in emerging products, such as media-related electronics…Seagate had been investing heavily in HAMR. Investing in these technologies and choosing whether to share or not is a strategic decision. Seagate had done a lot of work on HAMR, and the managers were reluctant to share HAMR technology with competitors. However, the rest of the industry was working on BPMR. Eventually, they (Seagate) felt the rest of the world going to another direction. If they had talked about what they have done on HAMR, the industry would have flocked into HAMR at that point in time. Seagate later on

[7] Perpendicular recording (or Perpendicular Magnetic Recording, PMR) is a technology for data recording on hard disks. It was first proven advantageous in 1976 by Shun-ichi Iwasaki, then professor of the Tohoku University in Japan, and first commercially implemented in 2005. Perpendicular recording can deliver more than three times the storage density of traditional longitudinal recording. There was some interest in using the system in floppy disks in the 1980s, but the technology was never reliable. Since about 2005 the technology has come into use for hard disk drives. Hard disk technology with longitudinal recording has an estimated limit of 100 to 200 gigabit per square inch due to the superparamagnetic effect, though this estimate is constantly changing. Perpendicular recording is predicted to allow information densities of up to around 1 Tbit/sq. inch (1000 Gbit/sq. inch). As of March 2009 drives with densities of 300-400Gb/in2 were available commercially, and there have been perpendicular recording demonstrations of 600-800Gb/sq. inch (Wikipedia. http://en.wikipedia.org/wiki/Perpendicular_recording.).

> continued to go down with HAMR and BPMR, both of which required huge R&D, and they lost a huge advantage in competition."

It should be noted that firms do not disclose all knowledge, neither do they disclose regardless of the characteristics of the technological knowledge they tend to disclose. As an industry analyst states:

> "The HDD firms that disclose or share technology do not take the open policy in a market stage where products have been fully developed. Rather, they open themselves when the technology is in a nascent stage, or when the products are not launched yet."

In the same light, a firm may decide to reveal its knowledge because its technology is on the frontier and thus it will not detract from the profits from a product innovation (Nelson, 1992). In this case, revealing technology does not provide a formidable threat because "imitation takes time, and by the time the imitation is achieved the initial innovator may have achieved a further improvement and extended the technological frontier." (Penin, 2007: p. 333)

The third need of the leading firms is to delay or prevent substitution by laggards, trading off with the erosion of imitation barriers to some extent. While leaders are constantly faced with imitation and substitution, the two competitive actions by rivals pose different threats. Namely, while substitution by competing laggards may not succeed in every case, when it does succeed, it poses a formidable threat to the leaders by disrupting the markets and displacing the existing innovations (Christensen, 1997). Proponents of resource-based theory (Barney, 1991; Dierickx & Cool, 1989; Lippman & Rumelt, 1982; Rumelt, 1984; Wernerfelt, 1984) suggest that firms can prevent imitation with resources that are not easily identified or controlled. However, setting up and maintaining imitation barriers is not a sufficient condition to prevent substitution from rivalry (McEvily et al., 2000). Competitors can pose substitution threats and disrupt the playing field of competition by overturning established business models and rendering incumbents' capabilities obsolete (Christensen & Bower, 1996; Tushman & Anderson, 1986). Moreover, it has been argued in prior studies that substitution threats are more formidable than imitation threats. For example, Yoo (2005) showed that late movers' resource substitution in the computer industry had a relatively larger impact than resource imitation on their returns as well as those of the first movers. Yoo argued that substitution strategies from late movers oftentimes reshape the competitive landscape, enabling them to overtake the pioneers over time. The higher impact of substitution is more vivid in high-technology markets (Golder & Tellis, 1993), of which the hard disk drive industry is a part. Janney and Dess (2006), give caution with respect to only focusing on imitation, contending that rivals faced with imitation barriers may seek out substitute resources, and eventually leave the focal firm more vulnerable in different areas of competition. Ma and Karri (2005) emphasized that preventing both imitation and substitution threats are key to a leading firm's success, but substitution may be more formidable since they are not easily detected by incumbents when new firms enter the market. They considered imitation as "chipping away" at the incumbents' advantageous positions and substitution as "moving the mountain and the sea," making the leaders' games irrelevant and their corresponding core competencies obsolete (p. 72).

Moreover, for the leading firm, oftentimes it is difficult to anticipate the potential substitution strategies of its rivals. For example, Ma and Karri (2005) argued that incumbents may not identify the substitutors as serious challengers due to the seemingly 'non-threatening' manner at the time of entry. In the same line, Christensen (1993; 1997; 2004; 1998) contended that business models from new entrants via substitution (disruptive innovation) are too small in terms of investment value or irrelevant to the incumbents' interests that the incumbents would not take competitive actions in entry stages. However, once the substituting business models or products have gained adequate market share in the industry, it is mostly too late for the incumbents to successfully react since they would have different resources, processes, and values that would not fit with the demanding expectations. Thus, regarding the formidable threat of substitution, leaders may have an incentive to disclose knowledge, fostering imitation and mitigate laggards' incentives to substitute.

2.2 LAGGARDS' INCENTIVES TO IMITATE KNOWLEDGE-DISCLOSING LEADERS

Prior studies have considered the motivations of interfirm imitation. For example, theories of organizational learning argue that imitating firms may learn from the successes and failures of early movers without having to bear the costs of experimentation (Dutton & Freedman, 1985; Haunschild, 1993; Levitt & March, 1988). Competitors are constantly searching for innovation opportunities, and an imitation strategy is a good stepping stone to enter markets or to launch new products, since it reduces uncertainty of demand. Strategic choice theorists suggest that first-movers in the competitive dynamics setting would have absorbed the market risk associated with product development and thus the late-movers may take advantage of the fact by imitating the products of the first-movers (Lieberman & Montgomery, 1988). In the hard disk drive industry, when a new component technology is introduced, it is not clear how large or how fast the market for the new technology would grow or whether it would serve the same customer base. For example, the market need for size reduction in hard disks have demanded better read/write heads with new architectures that may result in improvement of read/write speed. In turn, smaller size had derived new and unexpected demand growth such as PC computers for the 14 inch, 5.25 inch and 3.5 inch, and camcorders and pocket PCs for smaller hard drives. During the ‘change of demand’ periods many new entering laggards had failed by providing their own technologies and missing the moving targets. For the laggard, substitution may be riskier than imitation because the potential value of new technology (or new products) is not known and substantial effort may be required to persuade customers to switch from existing products. Particularly for new entrants, even when imitation may carry a competitive risk from leading firms who have become especially adept and efficient in using the dominant technology, entering markets through imitation may be quicker and less costly than entering via substitution (Barney, 1991; Powell et al., 2006). Namely, uncertainty reduction is a major factor which drives the adoption of technology (Rogers, 1995).

Institutional theory suggests that firms copy practices adopted by others in order to acquire legitimacy (DiMaggio and Powell, 1983). The knowledge of technologies or products that are disclosed or shared by leading firms signals the fact that they have already been proven within the organization and that they are ready for the market. Imitating these technologies or products would give the laggards the legitimacy that they are providing similar value-added products. The laggards will be suspicious of any attempt from the leaders to mislead them onto unpromising technology trajectories. The technological issues are evident (e.g. more bits per disk space or faster access speed), but the dominant technological standards that are accepted in the market to achieve the performance aspects are uncertain. In this sense following the buzz - which in some cases is laid out by the leading firms via publications, patents, and other channels - is the reasonable strategy to pursue for the laggards since it assures legitimacy. Note that imitating the firms in terms of technology does not equate to losing market share directly, since market share has other underlying mechanisms such as cost and price per unit. Namely, laggards are not misled into imitation, rather they are persuaded to take what they believe are legitimate paths to what would be accepted in the market.

Also, rivals are constantly searching for strategic information (Cyert & March, 1963; Katila & Ahuja, 2002), but this information may be costly. Moreover, due to cognitive limitations, managers may not know how or where to search for critical information, resulting in firms to follow boundedly rational routines (Coff et al., 2008; Cyert & March, 1963). Furthermore, due to high levels of competitive risk and uncertainty, information asymmetries among firms remains between "what is known by the inventor and what is seen and understood by others." (Coff et al., 2008: 8) Thus, managers often search for information and solutions in familiar technological territories, engaging in "local search," in order to understand and assimilate the information into their innovation efforts (Levinthal & March, 1993; Rosenkopf & Almeida, 2003; Stuart & Podolny, 1996).

An industry analyst and former Western Digital engineer stated:

> "We were always on a lookout for what the industry leaders were laying out every quarter. We looked at publications, patents, announcements and even cooperated with them to see where the frontiers were. We didn't want to shoot in the wrong way in terms of R&D."

A technology manager at Samsung Electronics mentioned:

"We played 'follow the leader' for a while, when anticipated a change in milestone technologies, such as form factor (size) changes or areal density leaps. Since directions were uncertain, we figured that it was at least safe to imitate them…..at least until we found ways to leap frog."

In these conditions, knowledge disclosure by leading firms may provide opportunities for the rivals to increase their familiarity with the promising innovations, meaning that their search activities may be either refined or broadened to meet the increasing technological demands of the market. For example, Seagate's open policy through technical committees on interface standards related to the AT Attachment (ATA) storage, which is utilized as the disk drive interface on most personal and mobile computers, served as a pool of conversations, networking and joint development with rivals. These committees, mostly initialized by leading firms such as Seagate, were utilized not only to acknowledge the technological requirements to enhance storage capabilities of hard disk drives, but to understand the pathways of the leader's technological development and influence focus of rivals' R&D efforts[8]. One of the potential effects of these open policies is that firms may imitate the knowledge disclosing firms at multiple levels, including technologies, components, products, and even business models, since they become more familiar with the main issues that "make the buzz." Consequently, what leading firms such as Seagate are expecting by disclosing knowledge through the open policy channels is to

[8] Based on conversations with hard disk drive managers and engineers. For example, Seagate was a major player in initiating technical committees such as T10 (www.t10.org) and T13 (www.t13.org).

promote component innovations that will sustain their current architectures in the hard disk drives.

In sum, laggards have high motivations to imitate the leaders' component technology that has been disclosed since: 1) it would cost them less to implement that technology; 2) the laggards can relatively easily implement the component technology since they would have a better understanding of it; and 3) the laggards might reduce the market risk of not meeting demand when introducing their own alternative technologies. Thus, the following should hold:

Hypothesis 1: Leading firms' knowledge disclosure of core technologies is positively associated with the likelihood of laggards' technology imitation.

Leading firms have the incentive to incorporate new component technologies into their own products quicker, since early incorporation of new technologies promotes faster learning. Moving down the learning curve quicker would render the leading firm a higher probability of prolonging its technological lead once rivals do start adopting the new technology. In high-velocity environments, firms are constantly competing for technological standards, and the earlier a next-generation technology is incorporated in its products the better the chance of gaining dominance against other substitute technologies. For example, the hard disk drive industry is characterized by rapid technological change, extremely short life-cycles, intense competition, and rapidly falling prices. Along with cost and price pressures from the major consumers of hard disk drives, the computer industry, these conditions have pushed firms to introduce smaller hard drives with higher capacity. The rapid changes in these technology standards (e.g. capacity, size [form factor], and read/write head architecture) have been problematic for many firms, and most of them have not survived the transitions. Firms that were late to the market with new innovations thus suffered a severe revenue penalty, preventing them from finding any customers and eventually being forced to absorb R&D costs and start alternative developments, or to exit the industry altogether (McKendrick et al., 2000).

By promoting imitation, leaders would have the lead time to develop new component technologies and incorporate them into their next-generation products. Due to the information asymmetry between the leading firms and the imitating laggards in terms of the value of the innovation, imitators incur a cost of monitoring the innovation and its application among leading firms. When rivals in established markets base their strategy on imitation, their technological innovations incorporated in their products tend to be based on incremental change (Ireland et al., 2003; Tushman & O'Reilly, 1997). This means that they will compete with established firms on similar architectures and performance measures. Established, leading firms will already have had experience and efficiency, especially when dominant designs emerge throughout the evolution of the industry (Utterback & Suaraz, 1993). Imitation will reinforce the value of the leading firms' capabilities (Reinganum, 1982) and as a consequence they will have dominance in terms of price- and time-based competition (Christensen et al., 1998). This would allow the leading firms to develop the next generation of technologies and introduce quicker innovative products that had incorporated these technologies. Thus, the following would hold:

Hypothesis 2: Leading firms' introduction of products with next-generation technologies occurs earlier as the level of the leading firms' knowledge disclosure increase.

Moreover, when laggards imitate new components in the leader's next-generation products, leaders can "lock-in" laggards by focusing on the leader's technology that has been disclosed. In the context of locking-in customers or suppliers, McEvily et al. (2002) considers lock-in as a strategy in the context of customers or suppliers making "firm-specific investments in skills, knowledge, equipment, and/or organizational processes to use or support a firm's products. (p. 301)" Customers or suppliers incur a significant cost when shifting their business to other firms, since existing assets lose value and since new skills and equipment may be necessary to use the other firm's product. Thus, it is expected that the firm's exchange partners will delay purchasing, or developing for, a substitute technology (Lieberman & Montgomery, 1988). I argue that not only can leading firms lock-in customers or suppliers, but they can also lock-in competing laggards and delay their introduction of new component technologies in their next-generation products. Firms that lag behind in terms of technological capability are constrained with their ability to fully explore alternative component technologies. Developing components based on next-generation technologies required investment in a range of various development processes, costing time and financial resources. Laggards in the hard disk drive industry, compared to the leading firms, are less likely to possess the leverage to simultaneously search for alternative technologies and incorporate them into their products, once they imitated the leading firms' new component technologies. Namely, laggards may lose incentive to incorporate new component technologies developed by their own development efforts when they imitate the leading firm's disclosed technologies. Consequently, by disclosing knowledge, the leading firms may prolong their technological playing field by quickly introducing their own technologies due to the imitation of the laggards. Thus, the following hypothesis would hold:

Hypothesis 3: Laggards' introduction of products with next-generation technologies occurs later as the level of the leading firms' knowledge disclosure increase.

3.0 SAMPLE AND DATA

The hard disk drive market is an ideal setting for my study as technologies change rapidly, creating new opportunities for innovative firms, which firms must manage vigilantly. For example, the capacity of the hard disk drive (HDD) roughly doubles every six months, and the product life cycle of the HDD itself is six quarters at most (Kumar & McCaffrey, 2003). It should be noted that I focus on the technology competition at the component level to examine the dynamics of leading firms' knowledge disclosure and laggards' competitive response. First, components in hard disk drives are complex and risky, and developing substitute components require fundamentally different sets of resources and capabilities, including different sets of engineering competencies, manufacturing equipment, manufacturing flow systems (Christensen 1998). Components such as the read/write heads and platters are the core components of R&D for the HDD firms. Namely, most drives are similar in terms of their form factor, but it is the components that are the dominant differentiating factor in terms of performance. Second, component innovation is a key focus of firms in a range of industries such as main frames (Iansiti & Khanna, 1995), photolithographic alignment equipment (Henderson, 1993), and cameras (Windrum & Birchenhall, 1998). In the hard disk drive industry, millions of dollars are invested in novel component technologies to create the next wave of technological opportunity, which will redefine the paths going forward. Hence, developing new component technologies is a means to shape the playing field across product generations.[9]

Another reason the hard disk drive industry is ideal to test my hypotheses is that it is a weak information protection (IP) industry. Namely, in a weak IP setting, there are various ways to invent around a component technology via substitution. In the hard disk drive industry, the knowledge appropriation value of patents have been low, meaning that firms were reluctant to patent their technologies for the purpose of protecting their technology-based performance advantage (Lerner, 1997). The implication of this is that when there are multiple ways to improve performance measures (e.g. areal density) IP protection from patents is weak. Thus, I emphasize that patenting in the hard disk drive industry has more disclosing effects rather than appropriation effects.

Data for the measurements were obtained from four sources: Disk/Trend Reports, Standard & Poor's Compustat database, Thomson Reuters' SDC database, United States Patent and Trademark Office (USPTO) database, and the National Bureau of Economic Research (NBER) version of the USPTO database (Hall, Jaffe, & Trajtenberg, 2001). For constructing my sample, I first identified the population of firms in the hard disk drive industry based on the Disk/Trend Reports from years 1987 to 1999. The report has been the leading market research publication in the disk drive industry, and has been used in various studies with respect to this industry (Christensen & Bower, 1996). It contains extensive data on product models, sales, technology and firm characteristics, all of which were used in this study. Although the Disk/Trend Report contains disk drive data from 1976, I included years from 1987 since years before did not contain consistent data on component technology that was of interest of this study.

[9] Refer to the Appendix for a detailed explanation of how hard disk drive manufacturers focus on component level technologies in R&D.

Also, the alliance data for hard disk drive firms from the SDC database starts from 1987. I filtered the observations of products of firms in several ways. First, following Lerner (1997), I deleted two specialized subclasses of drives whose specifications may not be comparable to others: "rugged" systems designed for military applications and hard-disk cards that are installed in expansion slots of personal computers. Second, a single drive may have alternative configurations. In this case, I treated each as a different hard drive. Third, firms would either acquire or become acquired by other firms. In this case, I treated the acquired and the acquirer as the same firm when the two firms were observed simultaneously within the one year window of my analysis.

For the categorization of leader and laggard, I relied on the Disk/Trend reports for technological level of each product (areal density) and also sales data at the firm level. Although the sales data are largely estimated, they are regarded by industry experts as being of high quality (Lerner, 1997).

For information on patenting by firms operating in the disk drive industry, I relied on data drawn from the USPTO database of patents and the National Bureau of Economic Research (NBER) Patent Citations Data File (Hall, Jaffe, & Trajtenberg, 2002). As Hoetker & Agarwal (2007) notes, the choice of patent classes to include in my sample involves a trade-off. Namely, including a broader range of patent classes means that a sample will include more inventive activity and will represent more patents. On the other hand, a broader the range of patent classes implies that the patents will have application outside one’s industry of interest. Following Hoetker & Argarwal (2007), I adopted a conservative strategy and restricted the pool of patents to the class most relevant to hard disks: U.S. patent classification code 360, dynamic magnetic information storage or retrieval. Moreover, I filtered the sample further by searching for keywords that contained technology descriptions of the core components of the hard disk drive, such as “read/write head,” “platter,” “recording material,” “substrate,” “voice coil,” and “thin film.” This filtering would ensure that the knowledge that has been disclosed by leading firms would be relevant to the core components that they had developed through R&D activities.

For strategic alliances among the hard disk drives firms, I used Thompson Reuters’ SDC database. This database has been commonly used for strategic alliance studies.

For Hypothesis 1, the level of analysis is firm-pairs of leading firms and laggards. Leading firms and laggards were categorized based on annual market share[10]. On average, the top ten leaders accounted for approximately 80% of market share each year. Firms that did not report financial data for measuring R&D intensity (R&D expenditure over total assets) which was used as the proxy for absorptive capacity were dropped from the sample. Firms that lacked controls were also excluded, resulting in 746 observations for the sample.

For Hypothesis 2 and, the level of analysis is the annual top ten leading firms in terms of market share in the hard disk drive industry, and an observation was made whenever a leading firm introduced a product that incorporated next-generation technologies. Observations were dropped due to missing values in the measurements of any of the variables, resulting in 1,725 observations for the sample.

For Hypothesis 3, the level of analysis is the annual top ten leading firms in terms of market share in the hard disk drive industry, and an observation was made whenever a laggard introduced a product that incorporated next-generation technologies. Observations were dropped

[10] I also considered leaders in terms of technology, measured by the average performance measures of the hard disk drives (e.g. bit per square inch, areal density, reading time), but there was no significant differences in the analyses. Moreover, on average annually, over 85% of the market leaders were technology leaders.

due to missing values in the measurements of any of the variables, resulting in 1,952 observations for the sample.

In the next section, for Hypothesis 1, I specify the variables, conditional logistic model and results. I then specify the variables, survival analysis model, and results for Hypothesis 2 and Hypothesis 3.

4.0 EMPIRICAL ANALYSIS FOR HYPOTHESIS 1

Hypothesis 1 states that leading firms' knowledge disclosure of core technologies is positively associated with the likelihood of laggards' technology imitation rather than substitution.

4.1 VARIABLES

4.1.1 Dependent Variable: Laggards' Imitation

Laggards' imitation (*imitation*) is a binary variable coded "1" if a laggard imitated the leading firm and "0" if it substituted the leading firm. As aforementioned, it is assumed that the conceptualization and operationalization of imitation and substitution are two ends of a continuum. Thus, a next-generation product that is introduced to a market by a laggard is either imitation or substitution, not both. Following studies that have used the HDD industry (Christensen & Bower, 1996; Ren, 2008), I looked at two core components of the hard disk drive (head and disk) and defined imitation if the laggards have used the same technology of the leading firms in each of the components. This history of the HDD industry shows that there were architectural changes in heads and disks between generations (such as the change in architecture when "Winchester Drives" were introduced), which represents a substitution in technology. The categorization of imitation and substitution was based on Jaffe's (1989) measurement of technological proximity, which is based on the "angular separation of the vectors." I use this by measuring the technology overlap of the components in the products that firms introduce in a particular market segment. Let f_{ik} be the fraction of firm *i*'s products that incorporates technology *k*. Then the vector $f_i = (f_{i1} \ldots f_{iK})$ locates the firm in a *K*-dimensional technology space. Technologically related firms are "close" to each other in this space, which is a proxy for imitation or substitution. The level of closeness between two firms *i* and *j* is calculated as:

$$L_{ij} = \sum_{k=1}^{K} f_{ik} f_{jk} \Bigg/ \left(\sum_{k=1}^{K} f_{ik}^2\right)^{1/2} \left(\sum_{k=1}^{K} f_{jk}^2\right)^{1/2}$$

The numerator will be large when most of *i*'s and *j*'s products incorporate the same technologies. The denominator normalizes the measure to be one if f_i and f_j are identical. L_{ij} will be zero for pairs of firms with no overlap in the technologies, and unity for firms whose distributions are identical; it is conceptually similar to a correlation coefficient. I then categorized imitation as observations with one standard deviation above the mean of the closeness level, and substitution as those with one standard deviation below the mean in terms of closeness.

4.1.2 Independent Variable: Knowledge Disclosure by the Leading Firm

Patent application is an important indicator of knowledge disclosure in that by filling for patents, the innovation that is identified and codified by inventors becomes part of the public record, and to some extent, filing for a patent indicates a decision to forgo the strategic motivations of secrecy (Coff et al., 2008). Namely, patent applications have disclosure effects, and examination of patents is also useful to identify the level of information released (Lhuillery, 2006). Prior studies have acknowledged that the usefulness of each patent may not be immediately obvious and information asymmetries may well exist between the inventor and others that scrutinize patents (Coff et al., 2008; Lhuillery, 2006). Nevertheless, studies have considered firms' strategic motivations of knowledge disclosure through patent application. For example, in the context of patent races, Baker and Mezzetti (2005) use a game theoretic model to show that firms defend themselves from rivals in the innovation competition. By disclosing through patents, leading firms may make it more difficult for rivals to patent inventions related to the disclosed information since "the invention must be that much better before it will represent a sufficient advance over the now-expanded prior art. (p. 6)" Namely, knowledge disclosure may thwart subsequent innovations to displace the rivals out of the race, or at least extend the race. Thus, the knowledge disclosing firms have a rational and strategic motivation. Lichtman et al. (2000) also shows that leading firms engage in knowledge disclosure through patents to reduce their rival's expected payoff, and to promote favorable licensing agreements. Other studies have considered patent application as strategic knowledge disclosure activities, such as De Fraja (1993), Jansen and Wzb (1996), Anton and Yao (2003), Bar (2006), Baker & Mezzetti (2005) and Lichtman et al. (2000).

I used the annual count of hard disk drive-related patents that were granted by the leading firms to measure knowledge disclosure by the leading firm (*knowledge disclosure*). This measure was weighted by the number of citations that a patent receives after it was granted. Studies of patenting suggested that 'citations received' is a commonly used indicator of its importance and value (Ahuja & Lampert, 2001; Coff et al., 2008; Fleming, 2001; Rosenkopf & Nerkar, 2001; Sorensen & Stuart, 2000), and thus has a tendency to gain more attention since patents with high citation rates represent "platforms for further innovations and may thus be associated with knowledge-based competitive advantages.” (Coff et al., 2008: 17) The USPTO website offers a patent search engine by criteria such as assignee name, title, abstract, and description/specification. These criteria were used to search for patents that were related to hard disk drive component technology. I also confirmed whether each patent was under the appropriate patent class according to the USPTO patent class system. Criteria for the patent classes were Dynamic Magnetic Information Storage or Retrieval (360), Electrical Systems and Devices (361), Data Processing (700 to 707), and Electrical Computers and Digital Processing Systems (708 to 714).

4.1.3 Control Variables

Prior research suggests that firms of different size engage in different types of innovation (Klepper & Simons, 1997). I measure firm size (*size*) for leading firms and laggards by total assets. Large firms may make greater disclosures to signal their competitive positions to the market since they have historically achieved higher profitability and have larger patent stocks than small firms (Lev & Penman, 1990). Compared to small firms, large firms may also face less imitation risk, may achieve lower marginal benefits from increasing the level of disclosure, and may experience weaker signaling effects of disclosure (James & Shaver, 2008). Also, prior research suggests that firm age (*age*) affects the rate at which firms innovate (Sorensen & Stuart, 2000). Another control variable is R&D expense (*R&D expense*), measured by annual R&D expense in millions of dollars from the Compstat files. R&D expense indicates the extent to which firms have different levels of innovation that might influence the level of knowledge disclosure (James & Shaver, 2008). I control for self citations of patents (*self citation*) for each leading firm – the more other firms cite the technology, the more likely it is to become disclosed since the innovation will have been disseminated more widely (Coff et al., 2008). Self-citation has been used as measurements for internal knowledge transfer and represents the extent to which the value of R&D is retained with the firm, expected to have an effect on knowledge disclosure (James & Shaver, 2008). The average backward citation (*backward citation*) level of the laggard, also known as 'prior art,' represents their knowledge stocks that has been utilized in their innovation efforts, that might affect the laggard's propensity to imitate the leading firm. Meanwhile, firms engage in the local search of innovation by monitoring similar technological domains, and it is the absorptive capacity of the rivals that make it easier to understand and assimilate the knowledge disclosed by the leading firms (Coff et al., 2008). Cohen & Levinthal (1989, 1990) argued that absorptive capacity, namely, the ability of a firm to absorb technological capabilities or knowledge outside its boundaries, is more valuable when spillovers are present. Several studies have tested the influence of absorptive capacity regarding knowledge disclosure in technology (Agmon & von Glinow, 1991; Gambardella, 1992; Rosenberg & Frischtak, 1991). They broadly support the argument that higher levels of absorptive capacity improve a firm's ability to exploit technical knowledge transferred from outside the firm (Mowery et al., 1996). A key assumption underlying Cohen & Levinthal's (1989, 1990) argument is that "exploitation of competitors' research findings is realized through the interaction of the firm's absorptive capacity with competitors' spillovers." I adopt the same assumption for the model introduced in my dissertation. While knowledge flows from the leading firms, it is the rivals' absorptive capacity that conditions the amount or quality of knowledge that they can recognize, assimilate, and apply to its strategic ends. Namely, if the rivals gain access to the leading firm's innovative knowledge and understands to an adequate extent the underlying processes that produced the innovative knowledge, they may imitate the leading firm to leverage its development costs. However, high levels of absorptive capacity may allow laggards to realize their innovation efforts and thus render them the ability to substitute the leading firms. Further, firms with low levels of absorptive capacity may introduce inferior but substitute products. Thus, the influence of laggards' absorptive capacity may be positive or negative. Absorptive capacity (*absorptive capacity*) is measured by the annual R&D intensity of each firm in my sample, namely R&D expenditures over total assets. Previous studies have commonly used R&D intensity as a proxy for absorptive capacity (Arora & Ghoshal, 1994; Cohen & Levinthal, 1989, 1990; Dushnitsky & Lenox, 2005). To control for unintentional imitation and substitution by laggards, I included the number of manufacturing and supplier alliances a leading firm has entered (*alliances*) as an indicator for a leading firm working to bring a technology to market (Coff et al., 2008). Lastly, year dummies were included to control for dominant designs in certain years and industry-wide shocks that could have an influence on firms' innovation activities.

4.2 MODEL: CONDITIONAL FIXED EFFECTS LOGIT

For Hypothesis 1, I estimated the probability of a laggard imitating[11] the knowledge disclosing leader using logit models with maximum likelihood techniques. The general likelihood function for logit is:

[11] As explained in the variables section, a laggard's imitation means that it imitated rather than substituted.

$$ln = \sum ln\, F(x_j b) + \sum ln[1 - F(x_j b)]$$

$$j \in S, j \in \sim S$$

where x_j represents all independent variables and S is the set of all observations j such that $Y_j \neq 0$, $F(z) = e^z/(1\ e^z)$. Since my data contain firms that are observed multiple times annually due to the dyadic nature of the data structure (firms disclose their knowledge to multiple competitors), the observations for each firm dyad are not independent of each other. In such cases, a common and recognized option is to estimate fixed-effects models to control for unobserved heterogeneity, namely, time-invariant factors associated with grouped observations (Lounsbury, 2007; Yamaguchi, 1996). I used the 'xtlogit' command in Stata 11.0 to estimate the conditional fixed-effects logit models, which have been commonly used for dyadic panel data in management research (e.g. Karim & Williams, 2010; Marquis, 2006; Marquis & Huang, 2009; Rao et al., 2001; Trinh & Mitchell, 2009; Yang et al., 2010). The model is:

$$y_{it}^* = x_{it-1}\beta + u_i + \varepsilon_{it-1}$$

$$y_{it} = 1\ if\ y_{it}^* > 0, and\ 0\ otherwise$$

where x_{it-1} are lagged values of the independent and control variables and the random effects u_i are realizations of independent draws from a normal distribution with zero mean and standard error σ_u. Specifying leader-laggard dyad effects should mitigate the possibility that the results are influenced by autocorrelation of errors within the dyads (Rao et al., 2001).

4.3 MODEL DIAGNOSTICS

I interpreted the regression coefficients using the method recommended by Tuma and Hannan (1984) and Long and Freese (2006). Unlike ordinary least squares (OLS) regression, logistic regression does not require normally distributed or homoscedastic independent variables (Safizadeh et al., 2008). For logistic regression diagnostics, I followed the UCLA Academic Technology Services on logistic regression diagnostics with STATA (Berry & Feldman, 1985; Long & Freese, 2006). To test multicollinearity, I used the 'collin' command in STATA 11.0 and obtained the variance inflation factor (VIF), an indicator of how much of the inflation of the standard error could be caused by collinearity. As a rule of thumb, a VIF of 10 or greater is a cause for concern. The average VIF for the variables in my model is 1.26, and the condition index, a measure of the overall covariation among variables in the model, is 2.15, below the suggested cut-off of 30 (Greene, 1993).

To check the linear relation between the independent variables and the dependent variable, I used a Box-Tidwell model (Box & Tidwell, 1962), which transforms a predictor using power transformations and finds the best power for model fit based on maximal likelihood estimate. All of the independent variables and the control variables showed *p*-values above 0.05, indicating that there is no need for further transformation of the independent variables for the model used in the analysis.

To test for the "goodness-of-fit," I used the Hosmer and Lemeshow's goodness-of-fit test. The main idea behind the test is "the predicted frequency and observed frequency should match closely, and that the more closely they match, the better the fit." The Hosmer-Lemeshow chi-squared of my model was 13.24 with a "probability > chi" of 0.10, indicating that the model fits the data well.

4.4 RESULTS

Hypothesis 1 predicted that leading firms' knowledge disclosure of core technologies is positively associated with the likelihood of laggards' technology imitation rather than substitution. Table 4 presents the descriptive statistics and pairwise correlations of the main variables of interest. Based on the correlations, none of the correlations among the independent and control variables are sufficiently high to warrant concerns about multicollinearity. The highest correlation, firm age and firm size is 0.49 ($p < 0.01$) and understandable given the characteristics of the hard disk drive industry, since firms that have a long history tend to have grown throughout the years. For example, the oldest leading firms are those that are large in size, such as Fujitsu and Toshiba. Interestingly, the number of manufacturing alliances and supplier alliances (*alliances*), an indicator for a leading firm working to bring a technology to market, has a statistically significant correlation of 0.29 ($p < 0.001$). Thus, a leading firm's alliances may be viewed as an additional channel of knowledge disclosure that affects the competitive actions of laggards.

Insert Table 4 about here

As shown in Table 2, the logistic regression is statistically significant, as evidenced by Log Likelihoods and Wald χ^2 tests. As can be seen in Model 2 in Table 5, the level of knowledge disclosure by the leading firm has a statistically significant positive effect on the likelihood of imitation of the laggard ($\beta = 0.38$, $p < 0.01$, SE = 0.02), supporting Hypothesis 1.

Insert Table 5 about here

5.0 EMPIRICAL ANALYSIS FOR HYPOTHESIS 2 AND HYPOTHESIS 3

Hypothesis 2 states that leading firms' introduction of products with next-generation technologies occurs earlier as the level of the leading firms' knowledge disclosure increase, and Hypothesis 3 states that laggards' introduction of products with next-generation technologies occurs later as the level of the leading firms' knowledge disclosure increase.

5.1 VARIABLES

5.1.1 Dependent Variable: Introduction of Next-Generation Product

The dependent variable for Hypothesis 2 is whether a leading firm introduced a next-generation product in a given month in the following year of its knowledge disclosure. The dependent variable for Hypothesis 3 is whether a laggard introduced a next-generation product in a given month in the following year of knowledge disclosure by a leading firm. The Disk/Trend database reports the shipping month and year of all hard disk drive products that had been introduced in the market during period of my sample, which is 1980 to 1999. A next generation product includes those that have incorporated technologies such as 'thin-film' heads and/or 'thin-film' coating of the disks, which are considered the core technologies in recording.

5.1.2 Independent Variable: Knowledge Disclosure by The Leading Firm

For Hypothesis 2 and Hypothesis 3, I used the annual count of hard disk drive-related patents that were granted by the leading firms at *t-1* to measure knowledge disclosure by the leading firms. This measure was weighted by the number of citations that a patent receives after it is granted.

5.1.3 Control Variables

I included controls to ensure that my findings are robust. For the same reasons in Hypothesis 1, I included the firm size (*size*) leading firms and laggards, leading firms' age (*age*), and self-citations of leading firms and the laggards (*self-citations*), leading firms' R&D expense (*R&D expense*), absorptive capacity of the laggards (*absorptive capacity*), and the number of manufacturing and supplier alliances a leading firm entered (*alliances*). Note that for Hypothesis 2, only the controls for leading firms were included since the dependent variable is the introduction of next-generation products of the leader, and the independent variable is knowledge disclosure by the leader.

5.2 MODEL: SURVIVAL ANALYSIS

I test Hypothesis 2 and Hypotheses 3 with survival analyses, of which the hazard rate is a central concept. Following Kalbfleisch and Prentice (1980), the hazard rate is defined as the probability that a firm exits the market in a moment *t* given that it has survived until this period and conditional on a vector of x_{it}, which may both include both time-varying and time-constant variables,

$$\lambda(t; x_{it}) = \lim_{dt \to 0} \frac{\Pr\,(t \leq T < t + dt \backslash T \geq t, x_{it})}{dt}$$

where T is a non-negative random variable (duration), which I assume continuous, so that λ(t) is an instantaneous rate of introducing a product with next-generation technology.

I used a Cox proportional hazards model to predict the hazard of introducing a product with next-generation technology incorporated in it in a given month, annually. The estimation is performed using the semi-parametric Cox Proportional Hazards model (Cox, 1972):

$$h(t; x_{it}) = \lambda_0(t) * \exp\,(x_{it}\beta)$$

where $\lambda_0(t)$ represents the baseline function obtained for values of covariates equal to 0 ($x_{it} = 0$). In this specification, the effect of the independent variables is a parallel shift of the baseline function, which is estimated for all those firms that do not introduce products with next-generation technologies up to a particular period. The baseline function is left unestimated and the model is estimated maximizing a partial likelihood function with respect to the vector of coefficients β without the need to estimate the baseline function (although it may be recovered non-parametrically). Since the baseline hazard function in the Cox Proportional Hazards model is left unestimated, the model addresses the potential problem of unobserved heterogeneity that may rise when the baseline function is not properly specified and when there are time-varying covariants in the model, which is the case of my study.

However, a potential issue is that some cases multiple products are assigned to the same leading firm. Specifically, 1,725 products were newly introduced by 25 leading firms for an average of 69 products per firm. Since some of the observations are likely not to be independent, we used the robust method of calculating standard errors and clustered the data by firm to relax the assumption of independence with respect to products introduced by the same leading firm (Coff et al., 2008).

5.3 RESULTS

Hypothesis 2 predicted that leading firms' introduction of products with next-generation technologies occurs earlier as the level of the leading firms' knowledge disclosure increase, and Hypothesis 3 predicted that leading firms' introduction of products with next-generation technologies occurs later as the level of the leading firms' knowledge disclosure increase. Table 6 presents the descriptive statistics and pairwise correlations of the main variables of interest. Based on the correlations, leading firms seem to be more prone to introduce a product with next-generation technologies when they disclose knowledge of technologies in the previous year. None of the correlations among the independent and control variables are sufficiently high to warrant concerns about multicollinearity. The highest correlation, firm age and firm size is 0.43 ($p < 0.01$) and understandable given the characteristics of the hard disk drive industry, since firms that have a long history tend to have grown throughout the years. For example, the oldest leading firms are those that are large in size, such as Fujitsu and Toshiba. A leading firm's size and the number of manufacturing and supplier alliances it entered also has a positive correlation of 0.29 ($p < 0.05$).

Insert Table 6 about here

As shown in Table 7, the model is statistically significant, evidenced by the Wald Chi^2 test (χ^2 = 12006.60, p < 0.001) and Log Likelihood (Log pseudo-likelihood = -31.94). The table includes odds ratios for each variable which indicate the extent to which changes in the variable increase (odds ratio >1) or decrease (odds ratio <1) the likelihood that the leader will introduce a next-generation product sooner. Model 1 shows only the control variables. Here, it is apparent that firms with heavily self-cited patents introduce next-generation products sooner. Specifically, a one unit increase in self citation in a patent of a leading firm increases the hazard of introducing a next-generation product sooner by 0.6 percent (odds ratio = 1.06). Firm size and R&D intensity raises the hazard rate of a leading firm to introduce a next-generation product sooner, while firm age reduces the hazard rate. Model 2, which is the full model, adds the independent variable associated with knowledge disclosure level of a leading firm. Here, knowledge disclosure by the leading firms clearly faced a higher hazard rate. Thus, Hypothesis 2 is supported since higher levels of knowledge disclosure by leading firms increased the likelihood that it they will introduce next-generation products sooner than their rivals. Namely, by disclosing knowledge, leaders can promote imitation and delay substitution by laggards, resulting in a quicker finish to innovation. More specifically, a one unit increase in a patent disclosure weighted by its citations received increases the hazard of product introduction by 1 percent (odds ratio = 1.01). Interestingly, the number of manufacturing alliances and supplier alliances a leading firm enters increases the hazard of introducing a next-generation product by 2.9 percent (odds ratio = 1.029), presumably indicating that alliances are also an important channel of knowledge disclosure.

Insert Table 7 about here

Hypothesis 3 predicted that laggards' introduction of products with next-generation technologies occurs later as the level of the leading firms' knowledge disclosure increase. Table 8 presents the descriptive statistics and pairwise correlations of the main variables of interest. Based on the correlations, laggards seem to be late in introducing a product with next-generation technologies when leaders disclose knowledge of technologies in the previous year. None of the correlations among the independent and control variables are sufficiently high to warrant concerns about multicollinearity. Again, the highest correlation, leading firm's age and leading firm's size is 0.42 ($p < 0.01$) and understandable given the characteristics of the hard disk drive industry, since firms that have a long history tend to have grown throughout the years.

Insert Table 8 about here

As shown in Table 9, the model is statistically significant, evidenced by the Wald Chi^2 test (χ^2 = 1450.48, $p < 0.001$) and Log Likelihood (Log pseudo-likelihood = -47.54). The table includes odds ratios for each variable which indicate the extent to which changes in the variable increase (odds ratio >1) or decrease (odds ratio <1) the likelihood that the breakthrough will be announced in the press. Model 1 shows only the control variables. The number of manufacturing alliances and supplier alliances a leading firm enters decreases the hazard of introducing a next-generation product, specifically by 1.5 percent (odds ratio = 0.995), presumably indicating that alliances are also an important channel of knowledge disclosure. Model 2, which is the full model, adds the independent variable associated with knowledge disclosure level of a leading firm. Here, knowledge disclosure by the leading firms clearly decreases the hazard rate of laggards quickly introducing next-generation products. Specifically, a one unit increase in knowledge disclosure through patents weighted by the citations received reduces the hazard by 3.4 percent (odds ration = 0.966). Thus, Hypothesis 3 is supported since higher levels of knowledge disclosure by leading firms reduced the likelihood that laggards will introduce next-generation products sooner than their rivals.

Insert Table 9 about here

6.0 DISCUSSION AND CONCLUSION

This study examined the effects of knowledge disclosure of leading firms on the competitive responses of competing laggards in the hard disk drive industry. It also examined how knowledge disclosure affects the competitiveness of a leading firm's knowledge competencies. In fast-paced environments such as the hard disk drive industry, innovation is not an easy task, since firms have to deal with high levels of uncertainty from outside and within the firm. From the outside, firms are often faced with hyper-competition (D'Aveni, 1994), an environment of frequent competence-destroying turbulence. Firms are often under the pressure to change, to creatively destruct their own competencies (Schumpeter, 1942) and to move quickly to build new advantages and erode the advantages of their rivals (Brown & Eisenhardt, 1998; D'aveni & Thomas, 2004). From within, firms are making large investments to develop new technologies, and oftentimes managers are faced with the challenge to discern the appropriate technology tracks their firms should commit to and which ones they should avoid. In turn, they are confronted with the uncertainty of setting straightforward strategic goals to be successful in the competition. However, once firms decide on pursuing certain technology tracks, they need to build some elements of stability into their capabilities. Namely, to some degree, firms need to consistently improve on exploiting their established technologies, or competencies, in order to reap the return on investments they have made. Thus, here arises the task to manage the need to change frequently yet perform reliably within each technology track. My dissertation addressed this issue of how does a leading firm sustain its knowledge-based advantage in a competitive landscape against threats of imitation and substitution?

The findings of this study show how leading firms might strategically address the paradox of disclosure, namely, why firms would disclose knowledge and risk drawing attention of its rivals (Arrow, 1962; Coff et al., 2006; Coff et al., 2008; James & Shaver, 2008). Evidence from the empirical analyses indicates that knowledge disclosure by leading firms in the hard disk drive industry is an important factor that influences laggards' competitive responses, namely, imitation and substitution. Also, leading firms that disclose knowledge of its current technological innovations have a higher probability of quickly introducing next-generation products. Further, knowledge disclosure of leading firms would delay substitute innovations of laggards, meaning that they might have turned the laggards' scope of search away from substitution as a competitive response. Thus, leading firms may promote imitation by disclosing knowledge and delay substitution by prolonging the value of their technological capabilities.

6.1 CONTRIBUTIONS TO THEORY AND PRACTICE

This study contributes to theories on competitive strategy (e.g. resource-based view, knowledge-based view, and competitive dynamics) by exploring how firms might address threats of imitation and substitution. The literature on the resource-based view (RBV) has paid less attention on how to avoid substitution threats compared to imitation threats. Moreover, the RBV rarely explores how managers may actively play a role in managing the knowledge boundary of the firm, namely, appropriating or disclosing strategic knowledge about capabilities (Coff et al., 2008). One of the basic assumptions of the RBV is that resources that have isolating mechanisms such as causal ambiguity, firm specificity, or social complexity make it difficult for rivals to imitate (Barney, 1991; Dierickx & Cool, 1989). However, such resources are not entirely inimitable since rivals may develop their own substitutes (Adner & Zemsky, 2006; Coff et al., 2008; Makadok, 2001).

Meanwhile, firms that compete in environments that are characterized as high-velocity (Eisenhardt, 1989) and hyper-competition (D'Aveni, 1994) are faced with high uncertainty and ambiguity in terms of technologies, pressured to make fast strategic decisions when searching for new innovations. In these situations it is vital how firms manage their knowledge-based competencies. Leading firms might affect laggards' scope of search by disclosing knowledge, a mechanism of managing knowledge boundaries, to allow imitation to some extent and gear them away from potential innovations that may pose a substitutive threat. Thus, managing knowledge competencies in high-velocity environments could be considered as a dynamic capability, the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments (Eisenhardt & Martin, 2000; Teece et al., 1997), to prolong their established competitive advantages.

I also contribute to the competitive dynamics literature. First, I build on the consideration within the literature that "the creative actions of leaders in pursuit of new opportunities elicit reactions from rivals in an attempt to destroy the advantages sought by the leaders." (Smith et al., 2001: 291) While it is important to examine the manner or process by which leaders and challengers act and react since it determines their performance and survival, my study attempts to "empirically identify strategic actions (knowledge disclosure) that will benefit from a delay in retaliation (delay in substitution), or making the moves as to maximize the delay." (p. 318)

Second, the consideration of knowledge disclosure as a strategic action broadens the scope of types of competitive behavior. Prior studies in the competitive dynamics stream have considered examples of strategic actions such as product introduction timing, advertisement polices, and market entry (Chen et al., 1992; Yu et al., 2009). However, there has not been much consideration on how firms make strategic actions and responses with their knowledge competencies. The results of my study indicate that knowledge-based strategic moves (knowledge disclosure) affect market-based strategic moves (product introduction). Also, Smith et al. (2001) emphasizes the context in which competitive actions and reactions take place and suggests that one of the uniqueness of competitive dynamics research has been the construction of samples of firms that are interacting with one another. Prior studies have examined samples from the airline industry (Smith et al., 1991), software producers (Young et al., 1996), and the stock market (Lee et al., 2000). My sample of the hard disk drive industry adds to this uniqueness in the sense that I have examined the vibrant context of strategic moves in terms of knowledge disclosure and product introduction in an industry where a high level of entry and exit has occurred.

6.2 LIMITATIONS AND FUTURE RESEARCH

This study has several possible limitations. First, I focus on a single type of knowledge disclosure (patents). Considering an attention-based view of a firm, all patents might be equal in offering a sufficiently reliable signal to influence rivals to take competitive actions (Coff et al., 2008). However, I weight the disclosure through patents by subsequent citations, which indicate the value of a patent and complementarily captures the meaningfulness of signals to rivals

(Harhoff et al., 1999; Podolny & Stuart, 1995; Trajtenberg, 1990). Nevertheless, my measurement of knowledge disclosure does not take into account the various and comprehensive effects of other knowledge disclosing channels, such as publications, announcements, research consortia, conferences, and alliances (Lhuillery, 2006). Scholars have argued that when firms build their knowledge base required to produce innovations, they do not solely rely on internal R&D investments but also turn to inter-organizational knowledge-diffusion networks (Almeida & Kogut, 1999; Jaffe et al., 1993; Wadhwa & Kotha, 2006). Strategic alliances serve as channels of inter-organizational information flow, providing a means to gain and accumulate new knowledge for technological development and to open up opportunities of learning from partner firms (Inkpen, 2000; Kogut, 1988). Different profiles of alliance partners reflect different resources and capabilities such as reputation, quality, and research and development technologies (Gulati et al., 2009; Rothaermel, 2001; Stuart, 2000), from which a focal firm may benefit when searching for new knowledge. Considering that an alliance network serves as a locus of innovation by providing access to knowledge and resources, how firms will strategically disclose its innovative knowledge and the effects of disclosure on alliance partners offers merit for future research.

Another limitation is that I consider only a one year lag as the period for competitive response (imitation and product introduction) to knowledge disclosure. Although I do not deviate far from the many studies in the competitive dynamics literature using one year as the ‘response window,’ my study does not capture long-term effects of competitive actions and reactions. Muller and Penin (2006) asserted that in the short run, disclosing knowledge is always profit decreasing for firms, but in the long run firms that have a high level of disclosure can be more profitable than firms with low level of disclosure, if they do not disclose too much knowledge.

Future studies may focus on the time dimension on competitive responses and how leader-laggard relationships evolve over time.

Lastly, my study does not focus on the various effects of knowledge disclosure on various players in the industry, including other leading rivals, suppliers, and other stakeholders. It may be interesting to examine, for example, whether the same type of knowledge disclosure has simultaneous but different effects among various strategic groups.

Another interesting future direction would be the clarification of how the absorptive capacity of firms may affect the relationship between knowledge disclosure and competitive actions. In terms of competitor identification (Chen, 1996; Peteraf & Bergen, 2003), a positive moderating effect of absorptive capacity on the relationship between knowledge disclosure and the probability of imitation may imply that leading firms may take into consideration the different effects of a strategic move on its rivals. More specifically, depending on the level of its absorptive capacity, a following rival may become a direct competitor, an indirect competitor (substitute), or a potential competitor (Chen, 1996). Since laggards that possess high levels of absorptive capacity may show a higher propensity to imitate the knowledge-disclosing leader, the leader might consider them as direct competitors. Also, potential competitors might become direct competitors or indirect competitors, depending on the change of absorptive capacity levels.

Table 1. Sales of IBM Plug-Compatible Disk Drives, by Manufacturer, 1976-1987

	1976		1978		1980		1982		1984		1986	
	$	%	$	%	$	%	$	%	$	%	$	%
Ampex	5.0	2										
Calcomp	20.1	8										
Control Data	12.6	5	48.1	12	69.8	19	82.8	15	20.0	3		
ISS/Univac	88.2	35	61.8	15	33.3	9						
Memorex	103.1	41	95.4	24	108.4	29	121.8	22				
Storage Tech.	21.4	8	132.7	33	148.0	40	299.2	53	127.5	21	129.5	22
Fujitsu							9.6	2	161.6	27	182.1	31
Hitachi					1.1	0	18.0	3	231.2	39	283.6	48
Nippon Peripherals			61.0	15			29.6	5	55.2	9		
Others	3.9	2			11.1	3						
Totals	254.3	100	399.0	100	371.7	100	561.0	100	595.5	100	595.2	100

Source: Christensen (1992)

Table 2. Top Ten Hard Disk Drive Firms by Market Share, 1987-1998

Rank		1987	1988	1989	1990	1991	1992
1	Firm	IBM	IBM	IBM	IBM	IBM	IBM
	$ Mil	6,844.4	8,973.9	9,650.3	11,979.1	11,313.9	9,373.7
	%	41.2	43.9	42.5	46.8	45.9	38.2
2		Fujitsu	Fujitsu	Seagate	Seagate	Seagate	Seagate
		1,482.7	1689.4	2,477.9	2,643.4	2,614.7	2,916.6
		8.9	8.3	10.9	10.3	10.6	11.9
3		NEC	Seagate	Fujitsu	Fujitsu	Fujitsu	Conner
		1,271.8	1,346.6	1803.2	1,898.6	1,861.3	2,234.2
		7.7	6.6	8	7.4	7.6	9.1
4		Seagate	NEC	NEC	NEC	Conner	Fujitsu
		1,065.7	1235.6	1,365.7	1350	1,567.6	1,588.7
		6.4	6	6	5.3	6.4	6.5
5		Control Data	Control Data	Digital Equipment	Conner	NEC	Quantum
		848.7	1,108.8	1,254.5	1,337.3	1,307.2	1,529.1
		5.1	5.4	5.5	5.2	5.3	6.2
6		Digital Equipment	Digital Equipment	Hitachi	Digital Equipment	Hitachi	Maxtor
		724.9	906.8	1170	1,195.5	1,187.3	1,299.9
		4.4	4.4	5.2	4.7	4.8	5.3
7		Hitachi	Hitachi	Conner	Hitachi	Quantum	Hitachi
		639.8	884.8	701.8	1,179.6	1,072.4	1,247.8
		3.9	4.3	3.1	4.6	4.4	5.1
8		Miniscribe	Miniscribe	HP	Maxtor	Maxtor	Western Digital
		361.1	570.3	533.4	779.5	928.5	941.3
		2.2	2.8	2.4	3	3.8	3.8
9		HP	HP	Miniscribe	Quantum	Digital Equipment	Digital Equipment
		328.1	402.6	469.1	710.1	776.4	886.9
		2	2.1	2.1	2.7	3.2	3.6
10		Micropolis	Micropolis	Maxtor	HP	Western Digital	NEC
		287.8	349.3	412.1	402.2	540.1	614.8
		1.7	1.7	1.8	1.6	2.2	2.5
	SUM	13,855	17,468.1	19,838	23,475.3	23,169.4	22,633
		83.5	85.5	87.5	91.6	94.2	92.2

Source: Christensen (2007)

Table 2. Top Ten Hard Disk Drive Firms by Market Share, 1987-1998 (Cont'd)

Rank		1993	1994	1995	1996	1997	1998
1	Firm	IBM	IBM	IBM	Seagate	IBM	IBM
	$ Mil	7,504.2	6,332.3	6,859.5	7,726.7	7,591.5	8,161.9
	%	34.5	27.3	25.8	26.8	23.9	27.1
2		Seagate	Seagate	Seagate	IBM	Seagate	Seagate
		2,940.1	3,770.4	5,140.7	7,024.8	7,284.9	5,942.9
		13.5	16.2	19.3	24.4	23.1	19.8
3		Quantum	Quantum	Quantum	Quantum	Quantum	Quantum
		2,001.1	2,900.6	3,845.4	4,372	4,921.1	3,717.2
		9.2	12.5	14.4	15.2	15.5	12.4
4		Conner	Conner	Western Digital	Western Digital	Western Digital	Fujitsu
		1800.7	1,962.2	2,291.1	3,533	4,236.3	3,021.9
		8.3	8.4	8.6	12.3	13.3	10.1
5		Maxtor	Western Digital	Conner	Fujitsu	Fujitsu	Western Digital
		1,204.1	1,717.9	2,219.7	1,306.1	2,266.8	2,871.9
		5.5	7.4	8.3	4.5	7.1	9.5
6		Western Digital	HP	Fujitsu	Maxtor	Maxtor	Maxtor
		1,098.8	1,103.5	1,383.1	1,072.2	1,421.6	2,408.2
		5.1	4.8	5.2	3.7	4.5	8
7		Hitachi	Fujitsu	Maxtor	NEC	Samsung	Samsung
		959.9	1038.7	1,241.2	706.9	731	1,077.8
		4.4	4.5	4.7	2.5	2.3	3.6
8		HP	Hitachi	HP	Hitachi	Hitachi	Hitachi
		943.8	864	729.8	409.1	416.3	629.4
		4.3	3.7	2.7	1.4	1.3	2.1
9		Fujitsu	Maxtor	NEC	Samsung	NEC	Iomega
		886.9	861.3	596.8	320.2	276.7	175.9
		4.1	3.7	2.2	1.1	0.9	0.6
10		Digital Equipment	Digital Equipment	Hitachi	Micropolis	Iomega	Syquest
		601.3	678	515.7	195.8	229.2	87.3
		2.8	2.9	1.9	0.7	0.7	0.3
	SUM	19,940.9	21228.9	24823	26,666.8	29,375.4	2,8094.4
		91.7	91.4	93.1	92.6	92.6	93.5

Source: Christensen (2007)

Table 3. Number of Hard Disk Drive Firms Introducing Models Equipped with Thin-Film Heads, 1987-1999

Year	Number of HDD Firms	Thin Film Heads
1987	60	18
1988	64	29
1989	64	33
1990	66	29
1991	63	28
1992	52	30
1993	43	27
1994	33	27
1995	30	27
1996	29	27
1997	24	23
1998	20	19
1999	20	19

Source: Disk/Trend Report

Table 4. Descriptive Statistics and Correlations of Variables for Hypothesis 1

	Mean	SD	Min	Max	Median	1.	2.	3.	4.	5.	6.	7.
1. $Imitation_F$	0.75	0.43	0.00	1.00	1.00	1.00						
2. Knowledge $Disclosure_L$	4,698.45	9,247.01	0.00	54,187.80	722.00	0.21**	1.00					
3. $Size_L$	12,626.40	2,914.53	28.6	101,869.54	11,287.37	0.23**	0.22*	1.00				
4. $Size_F$	1,631.78	1,922.68	6.50	7,845.12	1,266.80	0.26*	0.26**	0.25*	1.00			
5. Age_L	10.37	10.51	1.00	42.00	7.32	0.11**	0.14*	0.49**	0.24***	1.00		
6. R&D $Expense_L$	1,213.01	1,160.51	5.12	5,132.14	56.47	0.35	0.34*	0.28*	0.19**	0.26***	1.00	
7. Self $Citation_L$	0.65	0.08	0.00	0.25	0.03	0.16**	0.23***	0.04***	0.18**	0.21*	0.15**	1.00
8. Self $Citation_F$	0.05	0.04	0.00	0.20	0.09	0.07	0.12*	0.08**	0.06**	0.01	0.04***	0.04***
9. Backward $Citation_F$	5.02	2.98	0.00	15.12	8.45	0.01***	0.16***	0.23***	0.28	0.15***	0.32***	0.02**
10. Absorptive $Capacity_F$	0.12	0.15	0.08	0.21	0.08	0.07	0.15*	-0.07*	-0.11**	0.06*	0.03**	0.21***
11. $Alliances_L$	0.34	0.87	0.00	5.00	0.12	0.29***	0.34	0.38*	0.13**	0.31***	0.41***	0.13*

		8.	9.	10.	11.
8.	Self $Citation_F$	1.00			
9.	Backward $Citation_F$	0.14***	1.00		
10.	Absorptive $Capacity_F$	-0.12	-0.08**	1.00	
11.	$Alliances_L$	0.12***	0.18**	0.04***	1.00

n = 746, * p < .05, ** p < .01, *** p < .001, $_L$ = Leader, $_F$ = Laggard

Table 5. Logistic Regression Results for Laggard's Imitation

Dependent Variable: Likelihood of Imitation by Laggards	Model 1 Control Variables	Model 2 Full Model
Knowledge Disclosure$_L$		0.38** (0.02)
Size$_L$	0.14 (0.04)	0.35 (0.03)
Size$_F$	0.23 (0.16)	0.43 (0.08)
Age$_L$	2.73* (0.02)	3.66*** (0.00)
R&D Expense$_L$	4.25 (0.22)	5.12 (0.09)
Self Citation$_L$	9.24 (1.03)	1.30 (1.20)
Self Citation$_F$	-0.09 (0.01)	-0.12 (0.02)
Backward Citation$_F$	-0.19 (0.38)	-0.17 (0.39)
Absorptive Capacity$_F$	0.98 (0.38)	0.63 (0.89)
Alliances$_F$	1.33* (0.09)	2.09* (0.00)
Observations	746	746
Log Likelihood	-88.39	-114.48
Wald χ^2	123.45***	210.94***

* $p < .05$, ** $p < .01$, *** $p < .001$, $_L$ = Leader, $_F$ = Laggard

Table 6. Descriptive Statistics and Correlations of Variables for Hypothesis 2, Survival Analysis

	Mean	SD	Min	Max	Median	1.	2.	3.	4.	5.	6.	7.
1. Product Introduction$_L$	0.71	0.45	0.00	1.00	1.00	1.00						
2. Knowledge Disclosure$_L$	5,543.46	11,621.92	0.00	69,666.02	420.04	0.24**	1.00					
3. Size$_L$	17,057.02	24,478.01	55.99	102,714.80	5330.29	0.21***	0.25**	1.00				
4. Age$_L$	11.54	13.32	1.00	42.00	11.23	0.14***	0.22***	0.43**	1.00			
5. R&D Expense$_L$	1,122.38	1,332.66	5.69	5,522.28	462.21	0.25***	0.10**	0.37*	0.24**	1.00		
6. Self Citation$_L$	0.07	0.07	0.00	0.25	0.07	0.05*	0.25**	0.07***	0.10***	0.18***	1.00	
7. Alliances$_L$	0.44	0.96	0.00	5.00	0.00	0.28***	0.42	0.29*	0.19***	0.26**	0.21***	1.00

n = 1,725, * p < .05, ** p < .01, *** p< .001, $_L$ = Leader, $_F$ = Laggard

Table 7. Cox Proportional Hazards Model of Next-Generation New Product Introduction, Hypothesis 2

Dependent Variable: Product Introduction$_L$	Model 1 Control Variables	Model 2 Full Model
Knowledge Disclosure$_L$		1.010***
		(0.000)
Firm Size$_L$	0.999	0.999
	(0.000)	(0.000)
Firm Age$_L$	1.008	1.010
	(0.009)	(0.009)
R&D Expense$_L$	1.001	1.002
	(0.003)	(0.003)
Self Citation$_L$	1.060*	1.067*
	(0.001)	(0.021)
Alliances$_L$	1.032**	1.029***
	(0.000)	(0.000)
Observations	1,725	1,725
WaldChi^2	637.00**	12,006.60***
Log Likelihood	-32.18	-31.94

Standard errors in parentheses.
Odds ratios are shown. Ratios greater than 1 indicate a heightened hazard associated with the variable (those less than 1 mark reduced hazards).
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, $_L$ = Leader, $_F$ = Laggard

Table 8. Descriptive Statistics and Correlations of Variables for Hypothesis 3, Survival Analysis

	Mean	SD	Min	Max	Median	1.	2.	3.	4.	5.	6.
1. Product Introduction$_F$	0.53	0.50	0.00	1.00	1.00	1.00					
2. Knowledge Disclosure$_L$	4,957.32	9,923.00	0.00	57,275.25	410.83	-0.34**	1.00				
3. Size$_L$	16,866.00	4,214.42	55.99	10,2714.80	5,330.29	-0.25***	0.29**	1.00			
4. Size$_F$	1,613.03	2,074.34	11.04	8,530.64	558.44	0.28***	0.36**	0.29***	1.00		
5. Age$_L$	11.54	13.29	1	42	10.24	0.16***	0.24**	0.42**	0.25**	1.00	
6. R&D expense$_L$	1,113.17	1,325.91	5.69	5,522.26	462.21	0.29*	0.33*	0.27***	0.24***	0.23**	1.00
7. Self Citation$_L$	0.07	0.07	0.00	0.25	0.66	0.07***	0.26**	0.07**	0.13**	0.10**	0.19***
8. Self Citation$_F$	0.06	0.05	0.00	0.20	0.06	0.23***	0.13**	0.07*	0.08***	0.04	0.06***
9. Backward Citation$_F$	5.92	3.03	0.00	13.00	5.01	0.16***	0.26**	0.20***	0.21***	0.12**	0.23**
10. Absorptive Capacity$_F$	0.07	0.02	0.04	0.13	0.06	-0.02	0.20*	-0.08***	-0.06*	0.05*	0.07**
11. Alliances$_L$	0.41	0.94	0.00	5.00	0.00	-0.36***	0.46	0.28*	0.12**	0.22**	0.36***

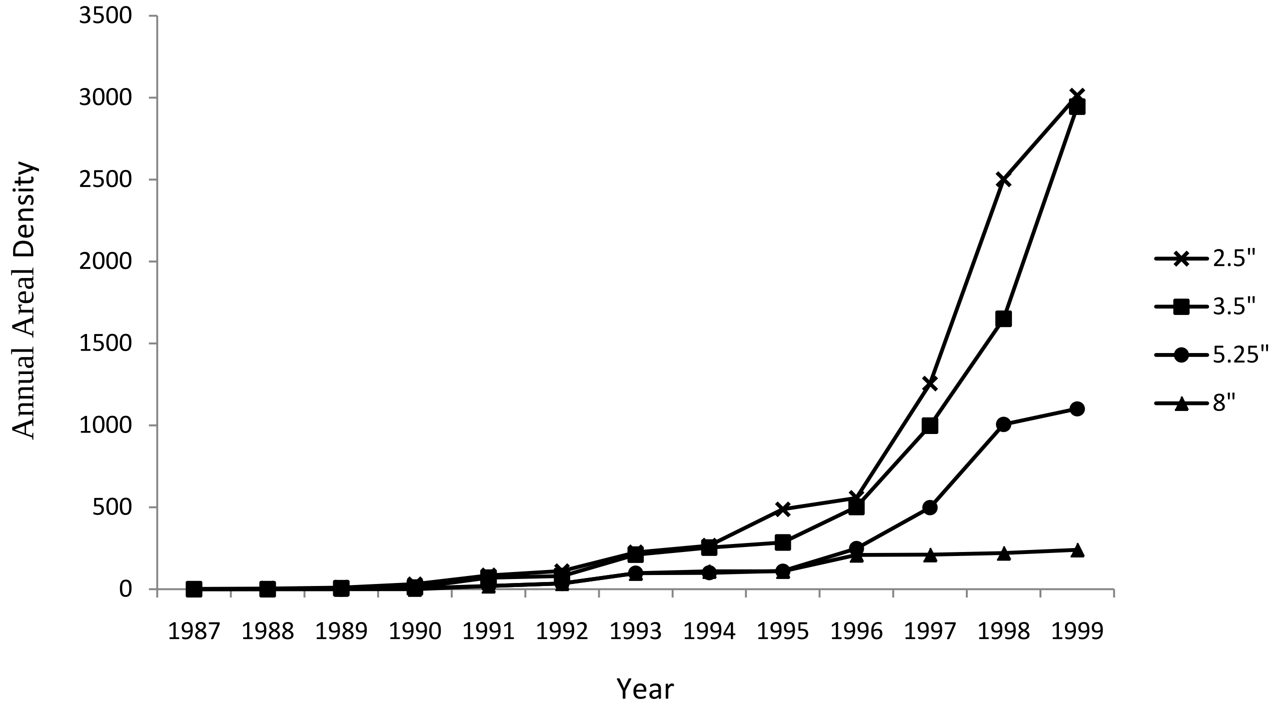
	8.	8.	9.	10.	11.
7. Self Citation$_L$	1.00	1.00			
8. Self Citation$_F$	0.09***	1.00			
9. Backward Citation$_F$	0.04*	0.15***	1.00		
10. Absorptive Capacity$_F$	0.29***	-0.07*	-0.02	1.00	
11. Alliances$_L$	0.20***	0.10***	0.28***	0.05*	1.00

n = 1,952, * p < .05, ** p < .01, *** p< .001, $_L$ = Leader, $_F$ = Laggard

Table 9. Cox Proportional Hazards Model of Next-Generation New Product Introduction, Hypothesis 3

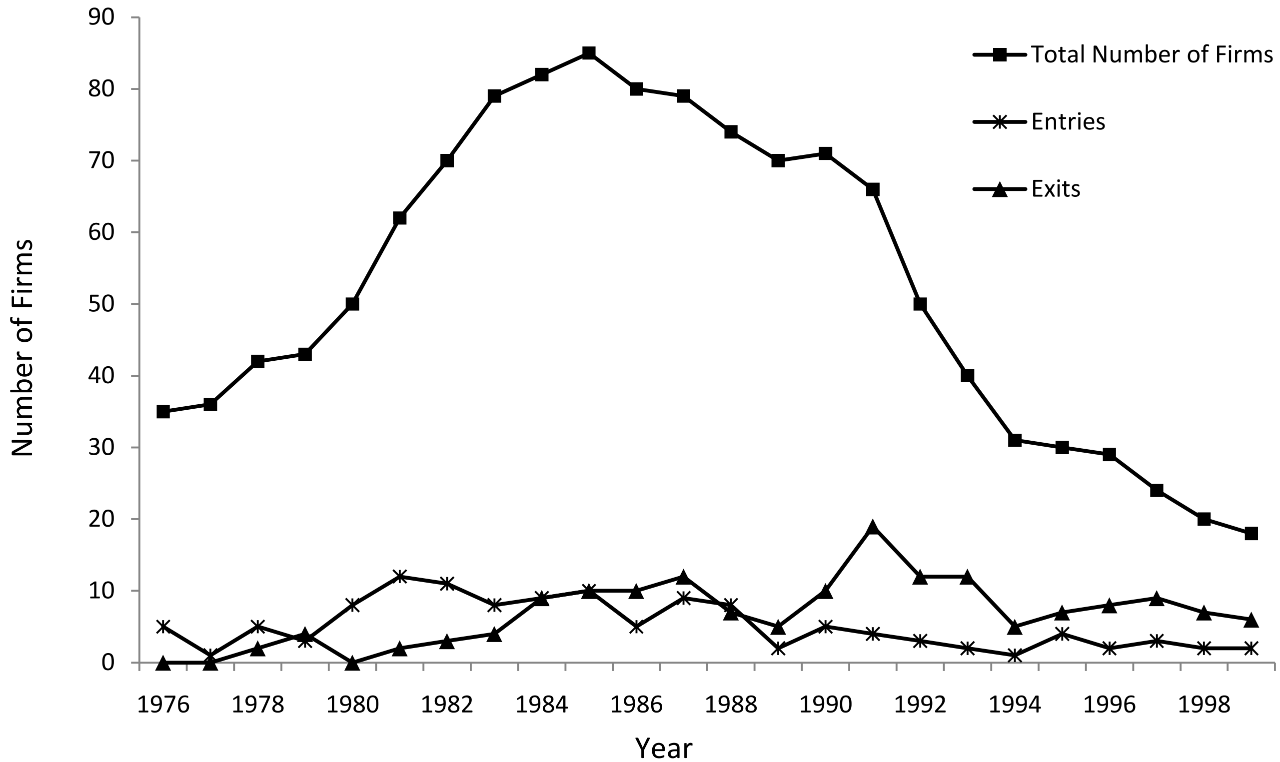
Dependent Variable: Product Introduction$_F$	Model 1 Control Variables	Model 2 Full Model
Knowledge Disclosure$_L$		0.966*** (0.000)
Size$_L$	1.000 (0.000)	0.999 (0.000)
Size$_F$	0.983 (0.024)	1.014 (0.001)
Age$_L$	0.986 (0.003)	1.056 (0.003)
R&D Expense$_L$	1.024 (0.031)	0.993 (0.021)
Self Citation$_L$	1.020 (0.077)	1.000** (0.189)
Self Citation$_F$	1.012 (0.000)	0.809 (0.084)
Backward Citation$_F$	0.909 (0.080)	0.878 (0.094)
Absorptive Capacity$_F$	0.926 (0.000)	0.992 (0.000)
Alliances$_L$	0.995* (0.000)	0.987** (0.000)
Observations	1,952	1,952
WaldChi^2	1,450.48***	1,300.97***
Log Likelihood	-47.54	-42.53

Standard errors in parentheses.
Odds ratios are shown. Ratios greater than 1 indicate a heightened hazard associated with the variable (those less than 1 mark reduced hazards).
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, $_L$ = Leader, $_F$ = Laggard



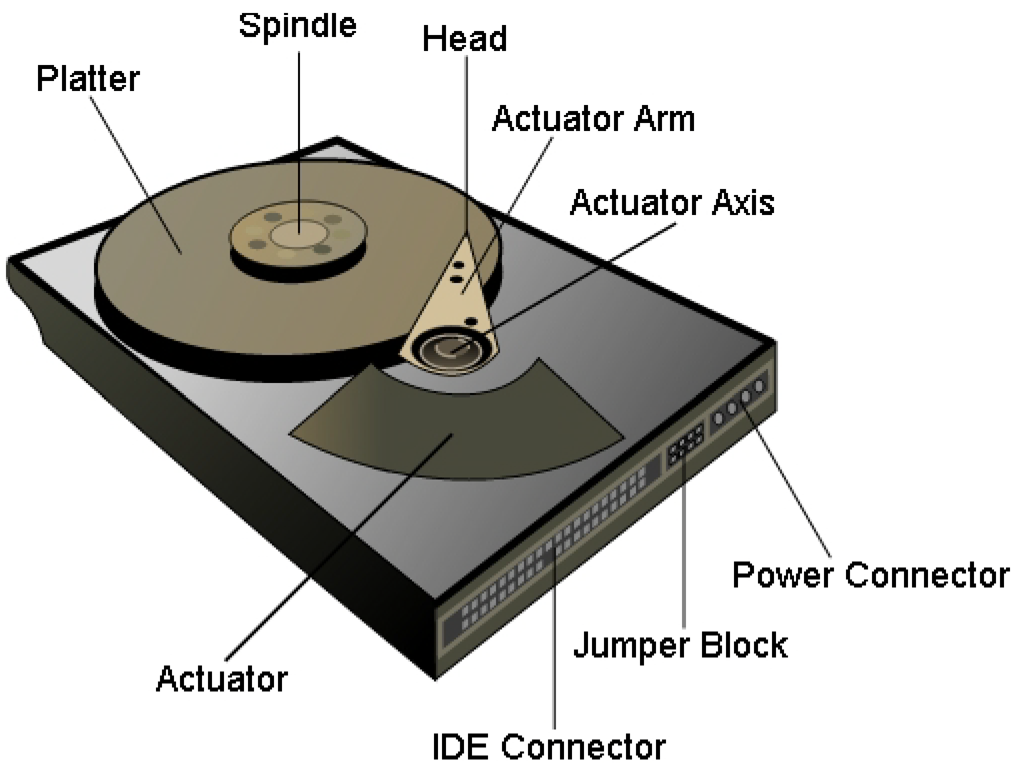
Source: Disk/Trend Report

Figure 1. Areal Density by Form Factor, 1987-1999



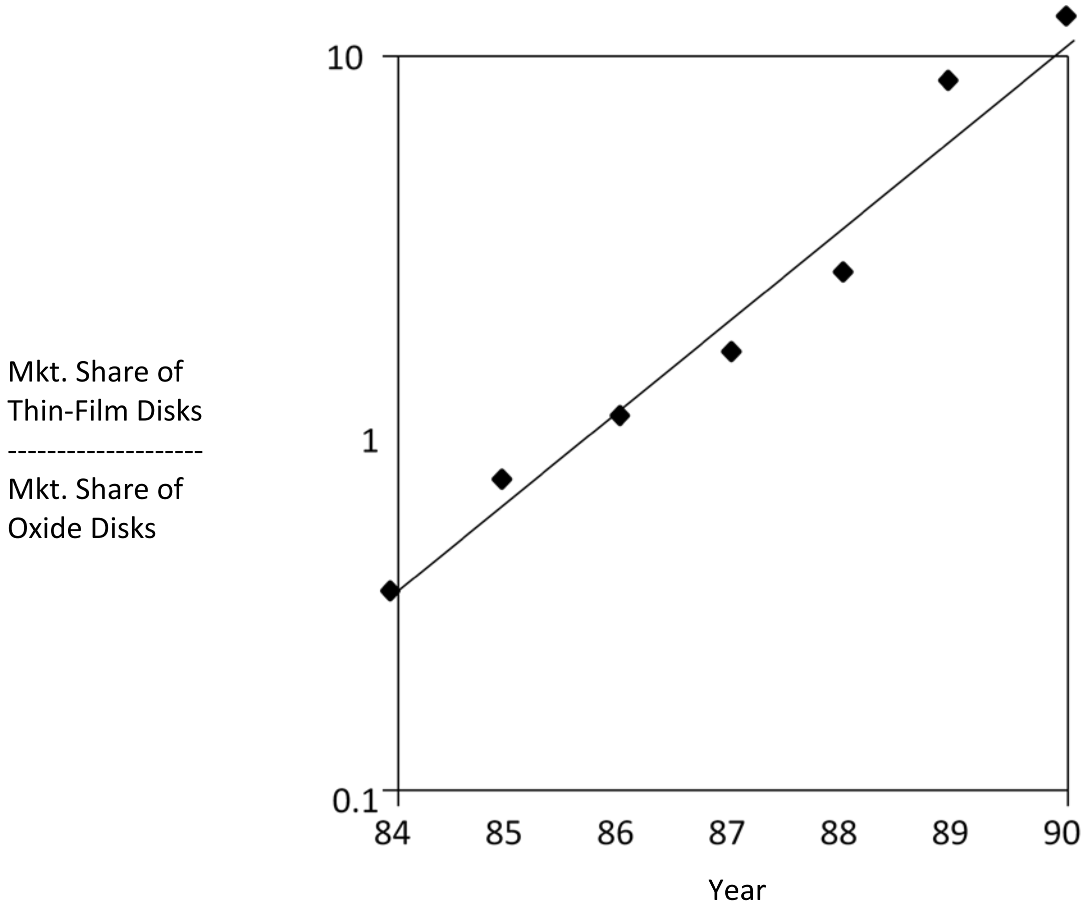
Source: Disk/Trend Report

Figure 2. Number of HDD Firms, Entries, and Exits, 1976 -1999



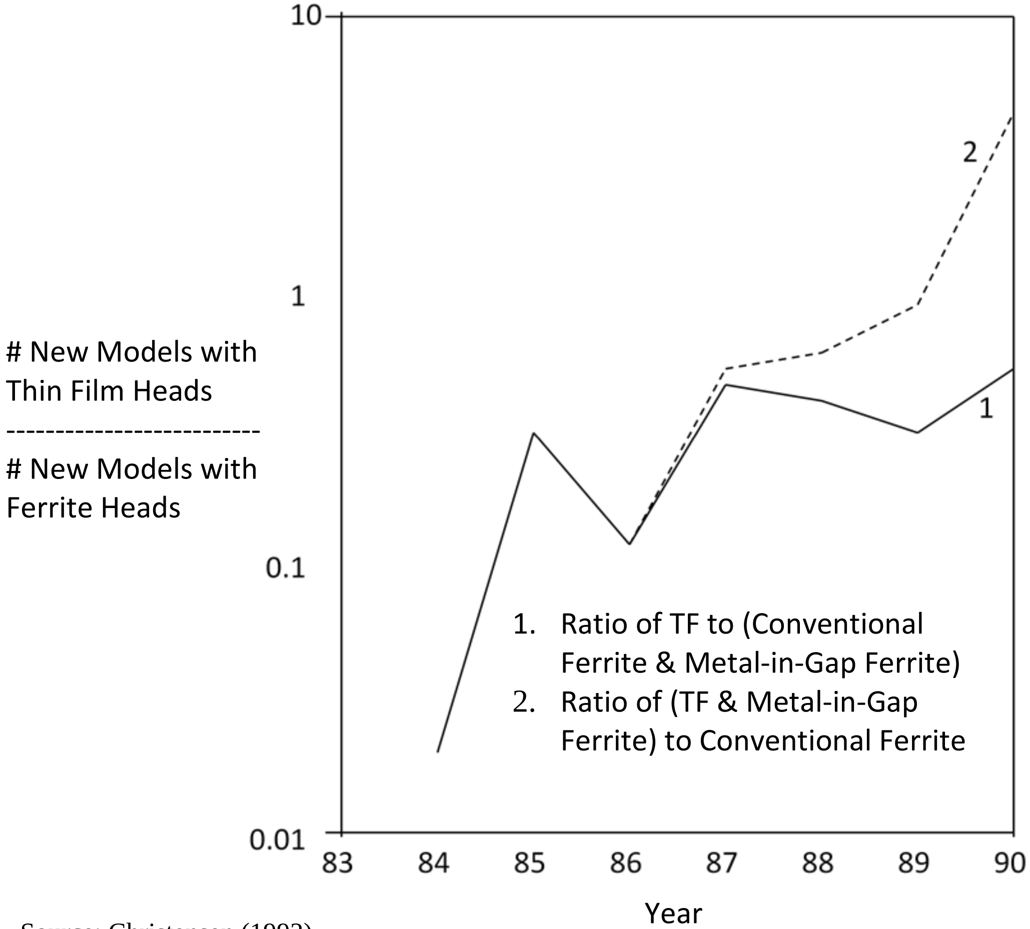
Source: http://en.wikipedia.org/wiki/File:Hard_drive-en.svg

Figure 3. Major Components of the Hard Disk Drive



Source: Christensen (1992)

Figure 4. Substitution of Thin-Film Metal-Coated Disks for Particulate Oxide-Coated Disks



Source: Christensen (1992)

Figure 5. Substitution of Innovative Head Technology for Conventional Ferrite Head Technology

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