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Competing Technologies and Industry Evolution: The Benefits of Making Mistakes in the Flat Panel Display Industry

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Abstract:
Managers at firms facing uncertain competing technologies evolving concurrently face a complex decision set, including options to invest in one technology or other, both technologies, or to wait to invest. This study investigates the role that experience, learning and timing play in affecting the firm-level pros and cons of each of these four strategies in a technological competition situation. Using a unique data set on the evolution of the global flat panel display industry, this study offers an example where firms that initially support the losing technology but later switch to the dominant technology actually exhibit the best performance. The study also suggests two simultaneous reasons for this advantage. First, there is a late mover advantage based on the timing of the technological commitments made by firms. Second, there is an early-mover advantage in broad technological learning that manifests as an increased ability to innovate, and this advantage is roughly one-third to one-half the size of the late mover advantage. Tracking the evolution of competition in flat panel displays, organizational decisions, and both product- and firm-level outcomes, this study provides insight into the competing factors that constrain and motivate managerial decision-making.

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INTRODUCTION

Technological uncertainty about the future trajectory of any given new technology creates challenges for managers assessing how to respond to the emerging opportunity. Dynamic environments moderate the likelihood of firms achieving high levels of performance based on early entry into new industries (Suarez and Lanzolla 2007), and the reduced expected return deters early entry (Christensen et al. 1998; Mitchell 1989).

Given the importance of uncertainty and risk, work addressing organizational response to an emerging new technology has generally focused on the question of *timing* of entry. Some research has suggested that early entrant firms may perform best (Lieberman and Montgomery 1988; Robinson et al. 1994), while others has suggested that late entrants will perform better, at least in a limited set of circumstances (Hoppe 2000; Markides and Geroski 2005). Similarly, in most of the classic technological entry studies in the literature – from Tushman and Anderson (1986) to Utterback and Suarez (1993), from Klepper & Simons (2000a) to Tripsas (1997) – focus on when firms do (or do not) jump from an existing technology to a new one.

Timing, however, is not the only choice facing managers. Competition between two or more uncertain, emerging technologies is a common occurrence and presents an additional layer of complexity for managers to cope with (Dranove and Gandal 2003; Kretschmer 2008; Postrel 1990). Instead of two choices (late or early), managers effectively face four choices – to invest early in option one, to invest early in option two, to invest early in both options, or to wait until the technological uncertainty has subsided. Research explicitly looking at technological competition generally provides insight into which technology may win and why (Arthur 1989; Schilling 1998), but has little directly to offer about how managers can and should deal with the uncertainty created by competing technologies. We therefore have little direct knowledge about the firm-level consequences of pursuing each of the four strategies available in a competing technology situation, which limits our ability as a field to offer constructive advice to managers about managing technological uncertainty.

The purpose of this study is to offer a theoretical and empirical look at the pros and cons of each of these four strategies in a single competing technological situation. Doing so involves building a theoretical case for each strategy based on entry timing, organizational experience, and organizational learning, as the effect of entry timing will be contingent upon industry dynamics (Suarez and Lanzolla 2007). Even with the limitations inherent to looking at entry choices within a single industry context, this study serves two important goals. First, this research fills an important and unstudied need within the literature. Second and more importantly, this research provides greater insight into the specific types of first- or late-mover advantages that may exist, hints at the relative size of those advantages, and links those advantages to the technological investment choices made by mangers.

The empirical context for this study is the global flat panel display industry, tracking the evolution of the two core competing technologies – liquid crystal and plasma – from the 1960s through the 2000s. The study utilizes a unique data set based on patents, product performance reviews, financial information, and market share to derive three key findings based on both product-level and firm-level performance. First, there is a late-mover advantage based on the timing of the technological commitments made by firms. Second, there is an early-mover advantage in broad technological learning that is available to all firms entering early irrespective of which technology they initially support, and that this advantage is roughly one-third to one-half the size of the late-mover advantage. Finally, the simultaneous combination of these two advantages explains the fascinating case discussed here where firms that initially supported the losing technology but later switched to the dominant technology actually exhibit the highest performance. Tracking the evolution of competition in flat panel displays, organizational decisions, and both product- and firm-level outcomes, this study provides insight into the competing factors that motivate and constrain managerial decision-making.

THEORETICAL DEVELOPMENT

Competing technologies (more than one technology vying either to create a new industry or replace an existing technology) have received a great deal of attention in the technology management and economics literatures. As stated earlier, most of this work has focused on the determinants of winners at the technology level. The seminal work by Arthur (1989) on the role of network externalities in creating a tipping point whereby late-adopting consumers flood to one technological alternative is a prime example. This is paralleled by management case studies of VHS versus Betamax (Cusumano et al. 1992; Rosenbloom and Cusumano 1987), research which addresses the processes that lead to technological success or failure in market-competition contexts. The literature on standard wars has extended this work and provided strategic advice to firms engaged in standard-setting discussions (Shapiro and Varian 1999; Tassey 2000). To the extent that any given technology is identified with a single firm (i.e. each firm has its own proprietary technology), then these studies have clear implications for firm strategy with respect to increasing the chance of success, as outlined by Schilling (1998). The goal of this study is not to look at why one technology wins and another loses, but instead top investigate what strategy may be most effective for a firm to take when faced with technological competition.

There is an extensive complementary literature on technological shakeouts in economics (Jovanovic and MacDonald 1994; Klepper 1996; Utterback and Suárez 1993). There is a common finding across these studies – that firms supporting the wrong technology will exit the industry – though each study proposes a slightly different mechanism and focuses on a single new technology replacing an existing one. Of particular relevance for this study, the shakeout literature highlights the importance of considering selection effects, a known problem for studies of entry decisions (Golder and Tellis 1993; Makadok 1998). It is clear, however, that exit need not always be the case from technological mistakes, as prior research has shown that when the new industry is of strategic importance to firms in other industries larger firms are more likely to be early entrants than smaller firms (Mitchell 1989; Thomas 1996). Given the resources and strategic imperative of large, early entrants, it seems likely that many firms supporting the wrong technology will switch to the new technology. One study that has looked at switchers directly (albeit from an existing technology to an emerging one) suggests that firms supporting the losing technology may be able to increase their survival chances from switching (Tegarden et al. 1999).

There is one technology management study that takes a firm-level view of technological competition. Schilling (2002) is primarily focused on using firm-level factors (such as learning orientation and entry timing) to understand the process of technological lock-out. The results show that entry timing influences which technology wins, and that technologies from firms with stronger orientations towards learning and adjustment fare better. As Schilling's study involves technologies tied to a single firm (i.e. Microsoft versus Apple), there is no discussion either of switching or of supporting both technologies initially. Thus the findings from that work are supportive of the need to take a firm-level look at technological evolution, but they are not necessarily instructive about the organizational consequences of resource allocation decisions under conditions of technological competition.

Despite the lack of direct studies comparing performance of firms making the four types of resource allocation decisions addressed in this study (firms backing the dominant technology from the beginning, firms switching to the dominant technologies, firms supporting multiple technologies, and firms entering late), the literatures on first mover advantages, organizational learning, and real options provide plausible explanations for expected superior performance for each group.

The case for firms that have backed the dominant technology from the beginning is largely rooted in advantages already identified in the first mover advantage literature. There are three likely sources of advantage available to firms aligned with the dominant technology initially. First, in situations where economies of scale may be available, building scale faster can provide a significant advantage versus later adopters (Bain 1956). Second, firms can create learning curve advantages, both in terms of manufacturing efficiency (Argote and Epple 1990; Wright 1936; Yelle 1979), product quality (Levin 2000), and technological knowledge (Cohen and Levinthal 1990, 1994). Finally, the earliest adopters of a technology would be likely to possess propriety intellectual property that might provide an important advantage as the technological space evolves (Gilbert and Newberry 1982). More broadly, early adopters may be able to control significant scientific resources (namely trained scientists) that increase the firm's ability to innovate effectively in the new technological industry. These three factors – economies of scale, learning, and proprietary knowledge assets – would be the likely sources of advantage for the earliest adopters of the dominant technology.

Firms initially backing both technologies are presumed to be pursuing a risk-minimization strategy. These firms would likely benefit from most or all of the sources of advantage due to early supporters of the dominant technology noted above. These firms are pursuing a real options strategy (Bowman and Hurry 1993; McGrath 1997), utilizing growth options in each technology as potential vehicles for future growth (Kulatilaka and Perotti 1998). Consistent with real options strategy, however, the overall level of investment in each individual technology is likely to be less than the investment made by firms completely supporting one technology or the other (McGrath and Nerkar 2004; Miller and Waller 2003). Thus, the benefits accruing to these firms would likely be less than those accruing to firms only supporting the dominant technology.

Firms that delay entry until after a reduction in technology uncertainty are also pursuing a risk-minimization strategy, albeit via different methods and with different advantages. In addition to numerous high-profile anecdotal late-movers who have dominated their industries, multiple theoretical models have addressed the circumstances under which firms might be better served entering later. The general principle in such models is that the development costs for pioneer firms will be significantly higher than for late adopters (Bayus et al. 1997; Hoppe 2000; Hoppe and Lehmann-Grube 2001), driven in large part by technological uncertainty and the potential costs of searching for the right solution. Additional research has shown a "technology vintage effect" (Bohlmann et al. 2002), where firms with the latest technology perform the best. This vintage effect provides late-mover advantages in contexts where the relevant investments are long-lasting ones. In a similar vein, Markides and Geroski (2005) suggest that late adopters can avoid making difficult-to-reverse commitments to inefficient technological processes by waiting to enter until after uncertainty subsides. Finally, research on entry timing and firm mortality in high tech industries has suggested that there may be a "window of opportunity" for firms to enter just before the subsiding of technological uncertainty, but when firms are less likely to make commitments to the wrong technological platform (Christensen et al. 1998). It is worth noting that the primary source of advantage for late entrants in a situation of technological competition is tied to the timing of the firm's *commitment* to a specific technological platform and the details of its manufacturing. Thus, any firm that commits late by delaying irreversible technological investments would benefit from this advantage, with late entrants simply being the most obvious example.

Firms that initially supported a different technology but later switched to the dominant technology, however, are another potential example of a firm that might benefit from committing later to the emerging dominant technology. Thus, firms that switch may be able to accrue some or all of the benefits of late entrants, albeit after suffering the lost investment in the losing technology. In addition, these switchers may be in a position to accrue other benefits based on their strategic investment decisions. Given that most research has traditionally considered only two real strategic choice possibilities – early and late – there has been no investigation of whether the benefits of being an early mover might accrue to firms other than those supporting the eventual dominant technology. While economies of scale and the ability to lock up technical assets (especially patents) may be tied specifically to support of the correct technology, firms initially supporting a different (but related) technology and later switching to the dominant technology may still accrue some learning benefits. Specifically, the potential benefits of absorptive capacity and learning in future R&D may be available to firms working in a similar technology to that that underlies the emerging industry (Cohen and Levinthal 1990, 1994). These firms are able to accumulate architectural knowledge about the design of products without locking themselves into specific component knowledge (Henderson and Clark 1990). Experimental work suggests that learning may increase if subjects are also doing “something else”, as they learn better from variation and relatedness (Schilling et al. 2003). Similarly, the opportunity for vicarious learning from the advances and mistakes of other firms may be more readily available for firms that are engaged in the emerging and uncertain industry, as opposed to late entrants (Miner and Mezias 1996; Nathan and Kovoor-Misra 2002). This perspective suggests that learning – about the new technology, about product design, about customer needs and wants, and about the activities of other firms in the industry – is much more easily done by being in the industry, as opposed to an outside observer. While these benefits clearly would accrue to early adopters of the dominant technology (including firms that supported both technologies), firms switching technologies may be able to take advantage of such avenues for learning, as well.

In lieu of offering formal hypotheses, this paper approaches the advantages and disadvantages faced by each of these four groups from a more exploratory perspective. In the following empirical sections, I will attempt to identify both the performance expectations for each group and the source of each advantage or disadvantage.

INDUSTRY HISTORY AND RESEARCH SETTING

The flat panel display industry is a fascinating industrial context, offering many technological choices, significant investment decisions, and a great deal of uncertainty throughout its history. This context differs from many other more common settings for technological evolution studies in a few important respects. First, since there were more technological choices than just the existing (CRT) versus a single emerging technology, there were additional strategic options available to firms that complicated decision making processes. Second, the future outcomes were non-obvious for a long period of time, as the setting does not feature significant network externalities may lead to a quick resolution of technological uncertainty. Similarly, as this story of technological competition in this industry is also less a story of proprietary IP than one of technological capabilities and knowledge, there were not overwhelming incentives for firms to enter the industry early to gain an advantage. Finally, many technological competition stories take place in the industry (such as HD DVD versus BluRay) or in standard settings bodies (such as the wireless telephone standards). In these cases, success or failure is as much about marketing or coalition-building prowess as about the technology itself. As described below, the evolution of the flat panel display industry has been one of the evolving ability of each potential technology to efficiently meet expected corporate and consumer needs. Thus, the competition played out (at least initially) in the R&D labs of firms around the world. This serves to reduce the entry costs for firms and to increase the importance of knowledge and technical capabilities. This combination of factors makes the flat panel display industry a fascinating one in which to study the implications of strategic choices under technological competition.

According to Display Source, one of the leading providers of data on displays, the 2006 flat panel display industry (panels only, not finished products) was around $85.5 billion worldwide, up 14% from

2004. Korean manufacturers LG Electronics and Samsung are the two leading branded suppliers, while Taiwanese companies AU Optronics and Chi Mei Optronics were two of the leading OEM providers. Despite the current dominance of Korean and Taiwanese manufacturers, however, the industry has long roots in both the U.S. and Japan. Consumer electronics and computer industry executives in the 1970s dreamed of wall-hanging flat panel displays that would replace conventional televisions and computer screens. Such visuals were prevalent in science fiction (*Star Trek* in the 1960s) and company brochures from the time. But executives faced very difficult resource allocation decisions. Two technologies showed potential promise to fulfill this vision, but each had its drawbacks and neither was considered a sure thing to replace the existing technology. What decision would lead to the best long-term outcome for the firm?

In the 1960s, research in several U.S. universities indicated the possibility of creating large flat panel screens to replace cathode ray tube (CRT) televisions and monitors that were prevalent at that time. In this early stage of the industry's development (1966 through the early 1980s), there were a number of competing technologies, most notably liquid crystal (LCD) and gas plasma displays. There was a great deal of uncertainty about which technology would develop into profitable products. Firms in this industry had identified key criteria for consumer acceptance (i.e. screen resolution, weight, power consumption, brightness, etc.), and the competition was a race to see which technology could deliver on these criteria in a cost-effective way. In this early, uncertain stage firms around the world made significant research and development investments hoping to achieve breakthrough discoveries that would make one of these technologies viable and establish it as the dominant technological trajectory. These firms came from a variety of backgrounds – television manufacturers, computer companies, watch companies, and makers of light emitting diodes (LEDs, the simple technology largely replaced by flat panels). But the majority of firms viewed the primary short-term application of flat panel technologies as enabling laptop computers, whether they were computer makers themselves or viewed this as an opportunity to supply that industry. [1] In this early period, some firms (such as Sharp, Toshiba, and General Electric) focused most of their

[1] All quotes and historical details used in this paper come from primary interviews conducted by the author with experts on the evolution of the flat panel display industry in the U.S. and Japan and from prior qualitative research on this industry (Matsui et al. 1997; Murtha et al. 2001).

attention on LCD technology, some focused on plasma technology (such as IBM, Fujitsu, and Sony), while some invested heavily in both (including Hitachi, Matsushita, and Siemens).

In the early 1980s, a series of technological advances led to the emergence of LCD as the dominant technology. The outcome was based on innovations related to the key criteria discussed above, and the success of LCD was relatively well-known for firms in the industry. Long-time industry insiders point to Seiko-Epson's appearance at the January 1983 Society for Information Display (SID) conference with a 1" color LCD television prototype as one of the most important events in the early evolution of the industry. While researchers in other firms knew that Seiko was working on such a device, the presentation of the prototype was an "eye-opening" experience for observers. One insider who was at the event called the product "spectacular" and another remembered telling his superiors that, "this could really be the key for the future of flat panels." The crowds at Seiko-Epson's booth and the discussions among the various attendees at the conference spurred R&D managers from firms that already had LCD investments to ask senior management for additional funding to pursue LCD technology, and led managers from firms pursuing plasma to question their commitment to plasma and consider reorienting around LCD technology. The result was that more than 20 other companies exhibited active-matrix LCD screens at SID events between 1984 and 1991 (Howard 1992). The growing interest in LCD technology in this period can clearly be seen from studying the patent records, shown in Figure 1. During the period 1983-1992 the aggregate patenting in LCD quickly passed that in plasma, the primary rival technology during the early period of the industry's evolution. A large number of firms both large and small entered the industry after 1983, including Samsung, LG and the current Taiwanese leaders. Despite these innovations in 1983, the first mass-produced LCD products did not begin to appear on the consumer market until 1987. Early large-format (11"+ screen) LCD products were entirely for laptop displays, with the next market being desktop displays and later televisions.[2]

[2] Submarkets exist for LCD signs, medical and military uses, but these submarkets are small and specialized, and so are not considered here. Additionally, there is a large market for small (<11") LCD screens for cell phones, GPS devices and other sues. This market is also excluded from this research as the players and key success factors have traditionally been different from those in the large-format market.

-- INSERT FIGURE 1 ABOUT HERE --

There are three samples of firms considered in this paper. The first sample, used only to address selection-related issues, includes the 1,422 for-profit firms with at least two LCD patents between 1966 and 2005, as identified in Derwent Innovations Index. The second sample, which is the main set of companies considered in this study, includes the 55 firms with at least one expert-reviewed (see below) large-format LCD panel product (694 products in total) manufactured between 1987 and 2005. This set covers all manufacturers globally where I could verifiably identify the manufacturer of the panel itself (not necessarily the brand stamped on the product at retail).[3] Finally, the third sample is derived from a snapshot of market share in 2005, a point when the large-format LCD panel industry had grown relatively stable, with changes in industry structure based largely on different investment patterns in large-scale manufacturing. There are 18 firms in the third sample with non-zero market share in at least one product market, but counting data from each of the three major markets for large-format LCD screens individually – laptop displays, desktop displays, and televisions – there are 39 firm-market observations in the sample. To deal with selection concerns between samples, I include selection controls for each nested sample, as discussed in greater detail below.

VARIABLES AND ANALYSIS

For this study I focus on two measures of performance – product value and market share. There is a long tradition in first-mover advantage studies of considering multiple measures of performance (Golder and Tellis 1993; Kerin et al. 1992; Robinson and Fornell 1985), and I choose these two as measures assessing different types of outcomes. I consider product value as a measure that is closely related to the outcome of the R&D and product development processes within the firm, which may be inherently tied to technological experience and decisions. Product value (or quality) is a common measure used in the product development literature to evaluate the success or failure of research and development processes (Harter et al. 2000; Sethi 2000). While such a measure may provide important insight into the efficacy of

[3] Panels for products from manufacturers such as Apple, Hewlett-Packard and Dell could not reliably be assigned to a specific panel manufacturer and are excluded.

the firm's R&D processes, there is a great deal more to firm profitability than simply creating good products. For this reason, I also discuss market share, which is highly dependent on the quality of the firm's commercialization capabilities and complementary assets. Both measures can provide interesting insights, as discussed below.

Dependent Variable: The primary dependent variable used in the analyses in this paper is a measure of product-level outcomes based on independent expert ratings of three categories of LCD products (televisions, monitors, and laptop screens) from a variety of manufacturers between 1987 and 2005. The variable is based on the actual product ratings hand-recorded from *Consumer Reports*, CNet.com, *PC World*, *PC Week*, *Government Computing News*, and LCDTVBuyingGuide.com. Data of this type has been used previously in other studies investigating firm-level innovative performance (Novak and Stern 2008). As each source uses its own scale, I have normalized each rating so that the final variable is expressed as the number of standard deviations above or below the mean for that source across the entire dataset. In cases where I have multiple ratings on the same product, I have averaged the ratings to ensure only one rating per product.[4] While every source's exact rating criteria is unique, the following excerpt from PC World's website is indicative of the overall criteria used: "The PC World Rating is the *overall rating* for a product, and results from the combined scores of four major component characteristics: features/ specifications, performance, design/usability, and price." Thus, the ratings are not intended to capture such strategic decisions as high quality/high cost versus low quality/low cost, but are meant to be comparable across market segments as measures of product "value". As a secondary measure of performance, I use a firm's market share in the specific product category (laptop screen, monitor screen, television screen). The measure of firm market share is taken from cross-sectional data covering 2005 global sales in the same three product categories – LCD laptop screens, LCD desktop display screens, and LCD television screens. The data come from iSuppli (www.isuppli.com), a highly-reputable private supplier of data on the global flat panel display industry to practically every major

[4] There are very few instances of multiple ratings on the exact same product (firm generally introduced multiple products with similar – but not identical – configurations). Thus there is no way to test inter-rater reliability.

corporation currently involved in the industry. As the variable is a percentage (share of total market, in terms of unit sales), I use a logit transformation of the variable.

Independent Variables: The primary independent variables tested are derived from patent records, drawn from the Derwent Innovation Index. Derwent provides two primary advantages in this industry to traditional USPTO patent data. First, Derwent provides records on patents from numerous countries (including USPTO data), appropriate for the global nature of this industry. Second, a primary value-add of the Derwent organization is much finer-grained categorization of patents than provided by the USPTO. This allows me to distinguish between patents for different flat panel technologies. The primary independent variables are counts of patents in LCD (PRE-1983 LCD PATENTS) and plasma (PRE-1983 PLASMA PATENTS) before 1983, when the core technological uncertainty in the industry was resolved for most firms. I use the count of patents for the firm in each technology as a means of identifying firms that made a significant early commitment to one or another of these technologies, or made significant investments in both (tested with the interaction of the two variables). Finally, for all firms whose first flat panel display patents occurred after 1983, I include a dummy (LATE TECH ENTRANT) for these firms.[5]

Control Variables: The primary empirical challenge for this paper is to deal with selection concerns. The essential concern is that those firms that initially supported plasma but later successfully switched to LCD technology are higher-quality firms on average, as the low-quality firms would have been unable to navigate the transition. Firms supporting LCD from the beginning, by comparison, faced a relatively lower selection environment and thus are more likely to be of mixed quality in the later (product value) sample. The most logical way to control for this selection effect is to perform a two-stage Heckman selection correction. However, doing so requires an accurate initial sample group of firms that

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[5] While the analysis shown here cuts off the "initial period" investments at 1983 as discussed, the results are robust to different timing periods with the following two exceptions. First, moving the early v. late distinction to later than 1985 begins to move large, successful firms such as Samsung and LG into the early entrant category, which depresses the later performance of the remaining late entrants. Second, moving the cutoff point for early patent investments past 1989 presents a problem for the count of plasma patents, as this marks the period where plasma technology reemerges as a viable alternative for the small niche of large-format televisions. Considering as similar plasma patents from 1979 (when there was a great deal of technological uncertainty in the market) and 1989 (when firms had a more realistic view of the future of plasma technology) does not make logical sense and clouds the interpretation of the results.

are “at risk” of appearing in the product value sample. I have data on all firms that patented in LCD or plasma technologies, but many of these firms were software firms (i.e. Microsoft), component part manufacturers (i.e. Corning), or other types of firms that never had any strategic intention of competing in finished flat panel display products. Thus, this would be an erroneous sample to consider “at risk”.

As an alternative solution, I have created a hazard rate model based on patent data to predict the likelihood that the firm would exit the technological space (cease all patenting in any flat panel display technology). The goal is to indentify how likely a firm with a given history of flat panel display patenting would be to leave the industry completely before any given subsequent year, with the idea that those firms that are least likely to continue operations and yet are still in existence are most likely to be “high type” firms. These firms would be expected to produce significantly higher value products than other firms in the sample. The model is a standard Cox proportional hazard model predicting the length of time any given firm exists in the flat panel display industry (as defined by patents). The model is similar to others used in studies of industry evolution (i.e. Klepper and Simons 2000b). The primary variables used are the count of patents in various flat panel (and related) technologies, each calculated as a five-year decaying stock of patents filed for (and later received), lagged two years. The technologies include LCD and plasma, as well as smaller technologies that emerged later (electroluminescence (EL), field emitting displays (FED), and organic light emitting diodes (OLED)), general flat panel display patents (applicable to more than one type of flat panel technology), and cathode ray tube (CRT) patents, targeting the incumbent technology. I also include dummies for the different stages of the industry (TIME1 being 1964 to 1982, TIME2 being 1983 to 1992, and the omitted category being 1993 to 2005). Finally, I include a CLOCK noting how many years elapsed for any given observation since the emergence of the industry (1966), DENSITY and its square counting the number of firms active in the technology space, and GROWTH, which notes the rate of growth in DENSITY from *t-2* to *t-1*. The resulting model is used to create a firm-year-specific cumulative hazard of exit based on the firm’s unique patenting history, which is entered as a control in the product value model (CUMUL EXIT HAZARD).

The remaining control variables included in the product value and market share models are a set of variables that are likely related to performance (product- or firm-level). This includes a measure of product market entry order (PRODUCT ENTRY ORDER, a traditional first-mover advantage measure), a dummy noting whether the firm had pre-flat panel experience in televisions or computers (as appropriate) (TV/COMPUTER EXPERIENCE, as such pre-entry experience has been shown to be important for performance (Cattani 2005; Klepper and Simons 2000a)), a measure of firm size (FIRM SALES, log transformed), a set of dummies noting corporate region of origin (JAPAN and US/EU, with the omitted category being from other parts of the world, primarily Korea, China and Taiwan), and a dummy noting whether the product in question is marketed by a firm other than the panel manufacturer (OEM DUMMY). The market share model also includes a control for the average product value rating (the DV from the product value model) for the firm in the prior five years (2000-2004) (LCD VALUE RATING).

Analysis Format: The primary sample comprises 694 products from 55 firms. The data are organized at the product level, so there are products nested within firms across 19 years in the data. With multiple observations for many firms (one for each product) I use a multi-level hierarchical model with random firm effects and clustered standard errors. I also allow for the potential that the firm-level random effect will be different depending upon the product category of the product (television, monitor, and laptop screen). Given the heterogeneous backgrounds of the firms in my sample and their differing levels of product development experience in each category, I allow this effect to vary across product categories. For the secondary (market share) model, I perform a standard two-stage least squares model with a Heckman selection correction (both stages shown below) with clustered standard errors (as I have as many as three observations per firm). The initial sample is all 55 firms on which I have product level data. The first stage instruments are the regional dummy variables, which logically reflect the cost disadvantages faced by more developed that forced many firms out of the industry. These variables have a significant impact on selection, but have little impact on market share.

The descriptive statistics and variable inflation factors (VIFs) are included in Table 1, with all data based on the product value model that comprise the core of the paper. Descriptive statistics on the market share models are excluded for the sake of brevity, but are available from the author upon request. In general, the descriptive statistics indicate a balanced sample, with approximately 63% of the sample from firms that entered the technological space before 1983, a balanced average investment in plasma and LCD before 1983, and good balance between products from Japanese (42%), US or EU (23%), or other firms. The one exception is the dummy noting whether the product is from a firm with prior television or computer experience – 93.5% of the products come from such firms. Thus, this control is unlikely to produce much of an effect (excluding it does not change the analysis). The VIFs are also generally modest, with the VIF for the LATE TECH ENTRANT variable being the highest at just over six. Combined with the fact that the model uses firm-level random effects (which helps alleviate concerns about time invariant controls such this variable), there are generally no concerns raised from this table.

-- INSERT TABLE 1 ABOUT HERE --

RESULTS

The results of the hazard rate selection model are reported in Table 2 on the full sample of firms with more than two LCD patents over their history. Model 2 looks for a consistent effect of patenting in plasma across all periods and shows no significant result, but Model 3 includes interaction terms between plasma patenting and the period dummies (to allow the effect of patenting in plasma to vary by period) and shows significant results. The results align very closely with the prior research on shakeouts in industries where one technology dominates another – the firms with a commitment to the losing technology are most likely to exit. The coefficients on the interaction term with the count of plasma patents and the period dummies are positive and significant ($p < 0.001$ before 1983, and $p < 0.01$ from 1983-1992), suggesting that greater firm-level research activity in the losing technology increases the hazard of exit across these periods. Again aligning with prior research and common sense, the effect is reversed in the latest period of the industry's history (1993-2005) when plasma reemerged as a viable alternative for large-scale televisions. Overall, the results of the hazard model suggest that firms with significant plasma investments early faced a more stringent selection environment than those firms that initially supported LCD, so those firms that survive the transition from plasma to LCD and produce marketable products later in the industry should be higher-quality firms. The results of Model 3 are used to create the CUMUL EXIT HAZARD used in the models in Table 3 below.

-- INSERT TABLE 2 ABOUT HERE --

The results of the main product value model are shown in Table 3. Interestingly, only two of the control variables show significant results. The coefficient for JAPAN (positive and significant, $p < 0.01$) supports previous research in the flat panel display industry indicating that the degree of knowledge sharing occurring in the evolution of this industry had a positive relationship with firm performance, and that Japanese firms were significantly more open to sharing information than companies in other countries (Spencer 2000). The other control that is significant (positive, $p < 0.05$) is the output of the selection model discussed above (CUMUL EXIT HAZARD). This result aligns with the earlier perspective that those firms that had the *highest* hazard rate and yet still produced LCD products later would be high quality firms and (in turn) produce higher quality products. Given the conflicting results in the literature on first mover versus second mover advantages (Golder and Tellis 1993; Suarez and Lanzolla 2007), it is not surprising that the entry order variable is not necessarily significant – there are no clear-cut first-mover advantages in this industry.

-- INSERT TABLE 3 ABOUT HERE --

In the full model (Model 4 in Table 3), we can see that two of the four independent variables used to identify firms following the four different strategies are significant. The variable for early adoption of the dominant technology (LCD) is *negative* and significant ($p < 0.05$), suggesting that firms with greater early patenting in the dominant technology actually produce lower quality products. Meanwhile, the coefficient on PRE-1983 PLASMA PATENTS is positive and significant ($p < 0.05$), demonstrating that the larger the firm's initial research activity in the losing technology (plasma), the higher the value of their subsequent products in the dominant technology (LCD). It is important to remember that this result holds true even with the inclusion of the CUMUL EXIT HAZARD control that captures the effect of selection based on the attrition of the lower quality firms initially supporting plasma. Finally, the two variables identifying risk-minimizing decisions – hedging (captured with the interaction term) and waiting (from the late entrant variable) – are not significant. These surprising findings will be discussed in greater detail below, after consideration of the market share model.

The results of the market share model (both the first and second stages) are reported in Table 4.[6] The model is a two-stage least squares model, with the first stage (selection) results listed below. While the first stage model is not the focus of this work, it does offer some insights. First, the region controls which comprise the identification strategy for the two-stage model produce the expected results, with firms from less-developed countries (namely Korea, Taiwan and China) being more likely to have a non-zero market share in 2005 (these countries are in the omitted third category, and the other two categories are negative and significant). Additionally, firms with early LCD patents ($p < 0.05$) and with higher rated LCD products ($p < 0.05$) are more likely to have a presence in 2005, which aligns with the suggestion that these firms have the greatest incentives to remain competitive in LCD products. Meanwhile, firms with previous television or computer experience are less likely ($p < 0.01$) to be active in 2005, which demonstrates that most denovo entrants to the LCD product space were likely to be aggressive and successful pure-plays (such as AU Optronics and Chi Mei Optoelectronics).

-- INSERT TABLE 4 ABOUT HERE --

The second stage, however, produces similar results to the product value model above. The two controls that are significant (TV/COMPUTER EXPERIENCE and the INVERSE MILLS RATIO from the first stage are both positive) generally perform as expected, though it is interesting that the control for product value is not significant. Of specific interest are the four independent variables related to the four strategies at the heart of this study. The results show that, once again, the greater a firm's early investment in the losing technology (plasma), the greater their subsequent performance in the dominant technology (in this case LCD market share). In the market share model, however, the coefficient on PRE-1983 LCD PATENTS is not significant, suggesting that early support for the dominant technology may not have the same detrimental market share effect that it had in the earlier product value model. In general, these

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[6] Note that, due to the small sample size and colinearity issues, some variables included in the product value models are excluded. Including any of these does not materially affect the core results.

results are consistent with the results from the product value model, specifically with respect to "switchers", even when controlling for selection concerns and observed product value (which we already knew would be higher for these firms).

Offering and Investigating Two Simultaneous Drivers of Results

The core results of the product value model provide a rank-ordering of the predicted product performance ratings for firms following each of the four strategies. The observed order is that early adopters of the dominant technology (LCD) fare the worst, risk minimizers (either through investing in both LCD and plasma, or through waiting to enter) are in the middle, and switchers from plasma to LCD perform the best. The earlier theoretical rationale for why switchers might be expected to perform well in terms of long-term performance had two components. First, there was an early-entrant advantage for these firms, potentially tied to absorptive capacity, the improved ability to learn vicariously, or the accumulation of relevant architectural knowledge. The important difference between this type of learning or knowledge accumulation is that it would have to apply to firms even if they were not investing in the (eventual) dominant technology. Most work on learning advantages for first-movers generally centers on learning curve effects that would accrue only to firms active in the eventual dominant technology. Instead, this type of learning advantage would need to be broader in scope.[7] The second theoretical advantage for switchers would be that they could gain the same benefits as late entrants, avoiding higher development costs and minimizing the chance of making inefficient technological investments.

These two advantages would not necessarily accrue only to switching firms, but switching firms would be the only ones with access to both advantages. For example, the learning advantage would logically be available to three types of firms – those initially supporting LCD, those initially supporting plasma, and those initially supporting both technologies. The late adopter advantage would primarily be

[7] Additional models which include a decaying, five-year stock of LCD citations in the product value model show that citations are positively related to quality, which suggests that there is a knowledge-based component of product value. The inclusion of citations in the model also eliminates part of the advantage of switchers, again suggesting that switchers may have a knowledge advantage. This model is available from the author upon request, but excluded here for brevity's sake.

available to switchers and late entrants, though firms investing at a low level in both technologies may receive some benefit if they are able to push off major investments through their hedging strategy.

In a crude attempt to understand the validity and relative sizes of these two effects, I calculate predicted product value ratings for *average* firms following each of the four strategies. I use the average count of pre-1983 patents in both LCD and plasma for firms investing predominantly in one technology or the other, or in both technologies, and multiply these by the coefficients reported in Model 4 in Table 3. This produces a set of predicted product quality values based on firm-level strategy. Based on the logic noted above, I then assume that all three early entrant firms will benefit equally from learning, while late entrants and switchers will gain the full benefit from late technological commitments and "hedgers" will gain half the benefit. This produces the values noted in Table 5, with the caveat that I look at two different sets of predicted values – those based only on significant coefficients and those using all coefficients. Solving the matrices of these two sets of values produces results that almost perfectly determine the predicted product value ratings for each type of firm (adjusted R-squared above 0.99 for either model). The results suggest that both the early learning and late commitment benefits are important for predicting value, and that the late commitment effect is between two (using only significant coefficients) and three (using all coefficients) times as large as the early learning effect. This analysis – while admittedly crude – produces results that agree with the theory offered earlier and suggest that while both benefits may be important, the benefits of committing late are larger than those from any early learning available.

-- INSERT TABLE 5 ABOUT HERE --

The presence of these two advantages was also in evidence from my conversations with managers and researcher engaged in the flat panel display industry in the 1970s and 1980s. Related to the mechanism for learning for all early entrants, managers from firms that successfully navigated the switch from plasma to LCD discussed how researchers that had previously been working on plasma were moved to working on LCD. One manager stated that researchers with prior experience in plasma had specific ideas for improving manufacturing of LCD panels that were particularly useful. This suggests that there was some useful knowledge accumulated from working on plasma displays initially, and that there was a ready mechanism (transferred research workers) to facilitate the reapplication of the learning. Related to the mechanism for late technological commitment, there were important technological developments within LCD technology during the 1980s that made delaying entry particularly beneficial. The first was that all initial research in LCD technology was in monochrome displays, as full-color displays were considered more difficult and there was skepticism about whether consumers would be willing to pay for color displays in computers. Many early LCD pioneers did most of their early work in monochrome displays, and presumably made investments to support this research as well. Second, there was underlying technological shifts within LCD technology as different variants vied for the position of dominant design. In the mid-1980s, the industry coalesced around thin-film transistor (TFT) LCD displays, abandoning research in passive matrix (PMLCD) and supertwisted nematic (STN) LCDs. Firms with significant early LCD research investments generally were active in all three of these technological designs, while late entrants (including, to some extent, switchers) were able to focus all energies on TFT LCDs.

Robustness Checks

I have not included the results of any robustness analyses in the paper, in part for the sake of brevity and in part because the changes do not materially affect the results in any way. There are five primary robustness checks that I have performed and report on below. First and most importantly, I have performed all analyses only on a subsample of early entrants (excluding those who had no patents in LCD or plasma before 1983). The biggest advantage of focusing only on early entrants is that it eliminates any concerns about the endogeneity of entry timing (i.e. Mitchell 1989). While this obviously removes the LATE TECH ENTRANT variable from the models, it does allow me to focus specifically on the three types of early entrants – LCD supporters, plasma supporters that later switch, and hedgers supporting both technologies. As mentioned above, the results are very similar for all models. Second, I have included a measure of product price for a subset of the products in the product value model. As the screen is only a small portion of the driver of price for laptops (as opposed to monitors and televisions), I excluded all laptop data from this model. I also do not have complete price data for all products. While the price variable itself was positive and significant, indicating that higher priced products received higher ratings despite the stated criteria of "value" as opposed to "performance", the inclusion of this variable did not affect the core results of the paper. Third, I have replaced the TV/COMPUTER EXPERIENCE variable with a continuous measure of market share in the relevant product category in 1983, again with no change. Fourth, I have performed product performance regressions with year fixed effects, to address the concern that late entrant firms might appear to have higher product performance based on increased average ratings over time. The year fixed effects were not significant individually or collectively (and thus were excluded to preserve degrees of freedom), and their inclusion does not change the core results. Finally, as discussed in Footnote 5 above, I have experimented with different ending windows for the early, uncertain period in the industry's evolution (currently set at 1983). Within reason, changing the window does not significantly affect the results. This makes sense as the first year of data in the product value model is 1987, so minor movements in the timing of transition from one period to another should have no impact on later outcomes.

DISCUSSION

This paper began with a simple question about the long-term performance implications of different strategic choices made by firms in an uncertain, competing technology situation. Managers possess at least four options – betting on technology one, betting on technology two, betting on both, or waiting until uncertainty subsides to enter. The results indicate that firms that initially supported the losing technology and later switched to the dominant technology produced the best products in the dominant technology and held the highest market share, even after controlling for selection and other important concerns. Firms that pursued risk-mitigation strategies, either by placing hedging bets on both technologies or by waiting to enter the industry after the uncertainty had subsided, performed worse than "switchers" but better (at least in terms of product performance) than firms that pursued the dominant technology from the beginning. This rank ordering of the firms – as well as the identification of at least part of the advantage of switchers as being due to increased rates of innovation in the dominant technology – suggests that there are two underlying drivers of the results. First, there is a late-mover advantage that allows both late entrants and switching firms to perform better than early adopters and (to a lesser extent) hedgers. Second, there is an early-mover learning advantage that applies not simply to early adopters of the dominant technology but to all early entrants into the technological space. These two effects are discussed in greater detail below.

The first identified advantage is tied to the timing of technological commitment. The idea that late entrants may be able to benefit from entering late is not new in the literature on technological evolution, with late entry being linked to lower development costs (Bayus et al. 1997; Hoppe 2000; Hoppe and Lehmann-Grube 2001) and avoidance of inefficient investments (Markides and Geroski 2005). In addition to providing some empirical support for this notion (though without a precise measure of the timing of technological commitment), one primary contribution of this study is to suggest that the benefits of committing late need not only accrue to firms that wait to enter the industry. Instead, in agreement with the idea of a technology vintage effect (Bohlmann et al. 2002), the benefits of committing late are tied to the timing of *investment* and not the timing of *entry*. Firms may be able to enter early (at least by some measures of entry) but make their technological commitments later, either through serendipity (as largely occurred in this study) or by design. The idea that firms may be able to intentionally put off irreversible investments aligns with work on strategic delay options (Huchzermeier and Loch 2001; Weeds 2002), and suggests that such options may be powerful ways for managers to cope with technological uncertainty. More work is clearly needed to understand the specific nature of the relevant timing of decision-making, and to further investigate how managers may be able to use the option to delay to their advantage.

The second advantage identified in this work relates to the ability of firms who have been actively engaged in the broad technological industry to accumulate greater knowledge (and be more innovative) than firms that enter the industry later. This suggests that early entrants are in a better position to learn from the evolution of and developments in the industry than outsiders. To the extent that the learning is broad and not specific, it appears as a story about absorptive capacity (Cohen and Levinthal 1990) and what underlying base of technical knowledge is helpful for the accumulation of additional knowledge (Cohen and Levinthal 1994). It is possible that these opportunities for learning come from the trajectory of the firm's own development efforts as it turns its focus towards the emerging dominant technology, or from vicarious learning from other firms in the industry (Miner and Mezias 1996; Nathan and Kovoor-Misra 2002). The data here do not really allow for teasing these mechanisms apart any further, but the key insight is that this class of learning appears to be broadly available to all firms engaged in the industry, and not only those that have chosen the dominant technology. This is an important insight for the first-mover advantage literature, which has often talked about learning advantages, but has largely considered those advantages to be about specific learning opportunities in the vein of traditional learning curves. Instead, there may be additional learning advantages that are broader in scope than those previously considered in the literature, and future research could obtain more detailed data to discover the exact nature of those learning advantages.

Obviously, this finding of a benefit from being late to commit the emerging technology while being actively engaged in the technology space is context-specific. This is especially true since I cannot measure how much money firms switching from the losing to the dominant technology. If however the overall cost of developing the dominant technology declined dramatically after 1983 as is suggested by work on second-mover advantages (Hoppe 2000; Hoppe and Lehmann-Grube 2001), then it is likely that these switching firms still spent less on their initial investments in the losing technology and moving to the dominant one than early adopters of the dominant technology spent honing and refining that technology. More importantly, the key finding of this research is <u>not</u> that managers faced with an uncertain technical space should enter early but should intentionally support the wrong technology. There are numerous reasons why switching from the losing to the dominant technology may be a challenge for firms (Eggers 2009), and the potential for an advantage from being a late switcher will be different in every context. But the underlying point is still there – timing of commitment to the dominant technology is an important consideration, and firms may still gain benefits from being engaged in the technological space even if they are not working on the eventual dominant technology. Researchers and managers should investigate both ways that firms can enter a technological space while delaying specific technological commitment as long as possible, and should also investigate how firms can better capture potentially useful knowledge from failed technological endeavors.

Overall, a primary contribution of this work is to build on Suarez and Lanzolla (2007) to argue for a reopening of the discussion of first-mover advantages. Much of the recent literature on the subject has investigated micro-level distinctions between markets to discern when first-mover advantages may or may not exit. This work suggests that the context of technological evolution may be particularly important. Additionally, to the extent that the goal is to offer better prescriptive advice to managers facing technological uncertainty, actually modeling the decision faced by managers – where there is real uncertainty about whether any given technology may actually revolutionize an industry – provides a great deal of additional insight. This study suggests that scholars interested in first-mover advantages may need to broaden their conceptualization of the types of learning advantages available, and to focus on the key elements of timing that are truly important. Finally, this study adds to our understanding of technological evolution by pointing out the importance that failed technological trajectories may have on long-term organizational path dependence and resource accumulation. More research should be done looking at the various implications of investments in such failed technological paths.

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Figure 1 – Study Timeline and the Emerging Dominance of LCD Technology

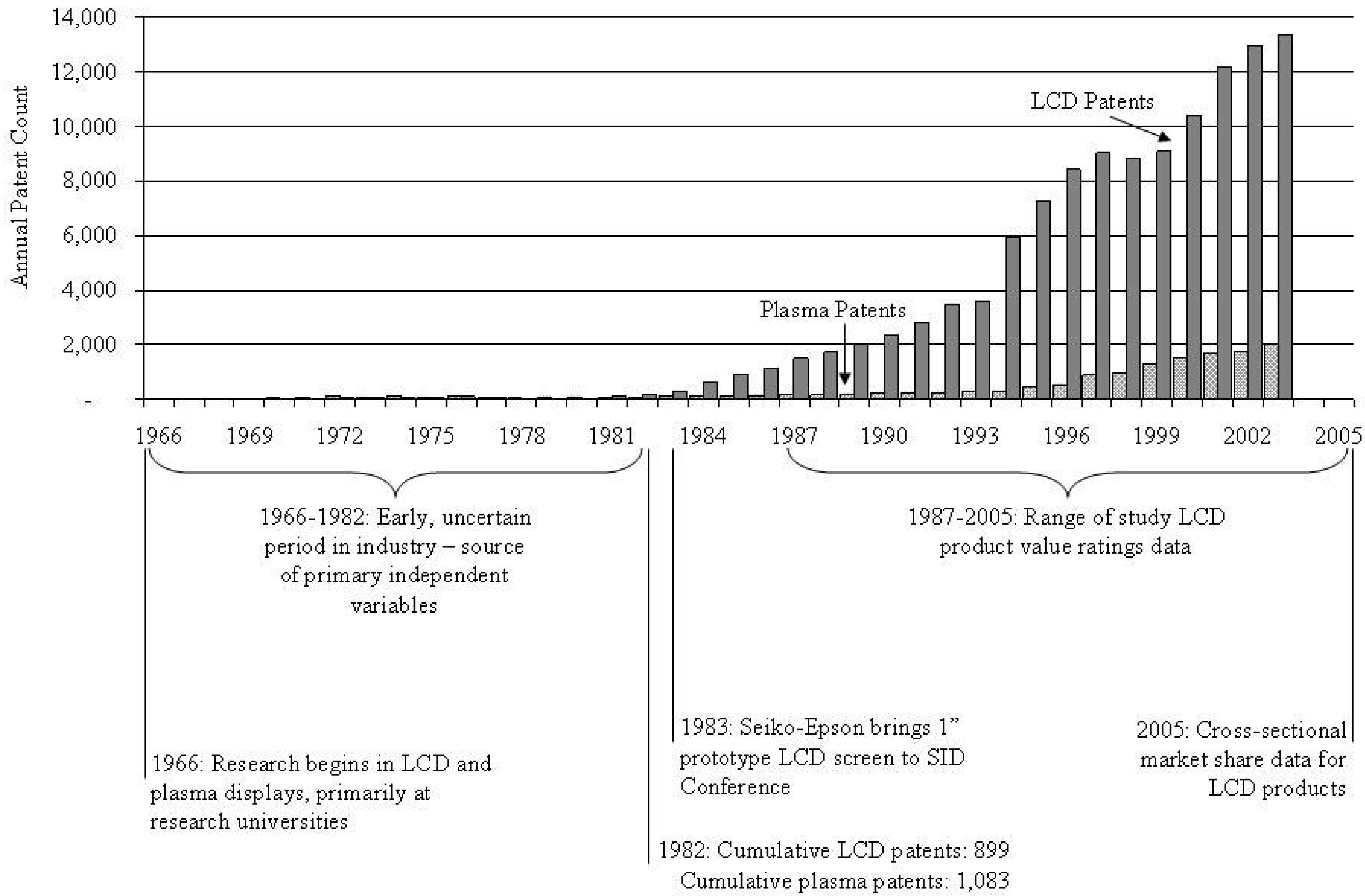

Table 1: Summary Statistics and Variable Inflation Factors (VIFs)

		Mean	S.D.	Min	Max	VIF
1	PRODUCT VALUE	(0.103)	0.977	(5.091)	2.256	
2	PRE-1983 LCD PATENTS (ln)	1.486	1.561	0.000	4.407	5.34
3	PRE-1983 PLASMA PATENTS (ln)	1.471	1.477	0.000	4.466	3.85
4	LATE TECH ENTRANT	0.372	0.484	0.000	1.000	6.11
5	PRODUCT ENTRY ORDER	18.438	13.449	1.000	55.000	2.31
6	TV/COMPUTER EXPERIENCE	0.935	0.246	0.000	1.000	1.32
7	FIRM SALES (ln)	2.447	2.293	(7.456)	4.629	3.17
8	JAPAN	0.418	0.494	0.000	1.000	5.42
9	US/EU	0.225	0.418	0.000	1.000	4.44
10	CUMUL EXIT HAZARD	21.123	17.717	(4.094)	71.645	1.98
11	OEM DUMMY	0.144	0.351	0.000	1.000	1.38
12	CATEGORY DESKTOP	0.526	0.500	0.000	1.000	2.28
13	CATEGORY TELEVISION	0.278	0.448	0.000	1.000	2.22
	n (Observations)	694				
	N (Firms)	55				

Table 2: Hazard rate of exit from technological space over evolution of industry (1966-2005)

	Model 1	Model 2	Model 3
PLASMA PATENTS[a]		0.017	-0.731 *
		(0.202)	(0.363)
* TIME1 (66-82)			1.489 ***
			(0.415)
* TIME2 (83-92)			1.215 **
			(0.429)
LCD PATENTS[a]		-0.090	-0.071
		(0.088)	(0.087)
CRT PATENTS[a]		-0.444 **	-0.475 **
		(0.148)	(0.150)
EL PATENTS[a]		-0.006	-0.029
		(0.163)	(0.165)
FED PATENTS[a]		0.382	0.626 **
		(0.539)	(0.218)
OLED PATENTS[a]		0.382	0.431
		(0.539)	(0.512)
GENERAL FPD PATENTS[a]		-0.196	-0.106
		(0.241)	(0.238)
TIME1 (1966-82)	2.984 *	2.941 *	2.529 ^
	(1.330)	(1.300)	(1.293)
TIME2 (1983-92)	1.592 **	1.638 **	1.486 **
	(0.491)	(0.492)	(0.510)
CLOCK	-0.425	-0.443	-0.423
	(0.272)	(0.273)	(0.272)
GROWTH	-3.538	-3.799	-3.318
	(3.744)	(3.759)	(3.800)
DENSITY	13.348 ^	13.728 ^	13.276 ^
	(7.935)	(7.929)	(7.927)
DENSITY ^ 2	-1.836	-1.925	-1.855
	(1.597)	(1.591)	(1.597)
Log Likelihood	-1062.9	-1050.78	-1044.35
n (Observations)	10510	10510	10510
N (Firms)	983	983	983

a: Calculated as a five-year decaying stock (linear decay), lagged two years

^: $p<0.10$ *: $p<0.05$ **: $p<0.01$ ***: $p<0.001$

Standard errors listed in parentheses beneath coefficients

Table 3: Effect of timing and technology decisions on product value ratings (1987-2005)

	Model 1	Model 2	Model 3	Model 4
PRE-1983 LCD *PLASMA PATENTS				0.006
				(0.083)
PRE-1983 LCD PATENTS (ln)			-0.197 *	-0.200 *
			(0.090)	(0.093)
PRE-1983 PLASMA PATENTS (ln)			0.220 **	0.221 *
			(0.079)	(0.096)
LATE TECH ENTRANT		0.174	0.267	0.253
		(0.251)	(0.282)	(0.363)
PRODUCT ENTRY ORDER	0.002	0.002	0.003	0.003
	(0.006)	(0.006)	(0.006)	(0.006)
TV/COMPUTER EXPERIENCE	0.110	0.127	0.106	0.103
	(0.227)	(0.228)	(0.230)	(0.234)
FIRM SALES (ln)	0.036	0.045	0.030	0.028
	(0.029)	(0.032)	(0.032)	(0.033)
JAPAN	0.424 ^	0.532 ^	0.847 **	0.860 **
	(0.226)	(0.275)	(0.302)	(0.311)
US/EU	0.093	0.173	0.178	0.180
	(0.204)	(0.236)	(0.231)	(0.237)
CUMUL EXIT HAZARD (ln)	0.006 *	0.007 *	0.007 *	0.007 *
	(0.003)	(0.003)	(0.003)	(0.003)
OEM DUMMY	-0.037	-0.040	0.025	0.024
	(0.142)	(0.142)	(0.142)	(0.143)
CATEGORY DESKTOP	0.087	0.074	0.058	0.060
	(0.125)	(0.126)	(0.137)	(0.137)
CATEGORY TELEVISION	-0.450 **	-0.451 **	-0.433 **	-0.437 **
	(0.152)	(0.152)	(0.156)	(0.159)
CONSTANT	-0.654 *	-0.828 *	-0.944 *	-0.952 *
	(0.288)	(0.381)	(0.374)	(0.382)
Log Likelihood	-941.164	-941.39	-940.114	-941.70
n (Observations)	694	694	694	694
N (Firms)	55	55	55	55

^: p<0.10 *: p<0.05 **: p<0.01 ***: p<0.001
Standard errors listed in parentheses beneath coefficients

Table 4: Effect of entry timing and tech decisions on market share (2005)

MARKET SHARE MODEL	Model 1	Model 2
PRE-1983 LCD *PLASMA PATENTS		-0.116
		(0.258)
PRE-1983 LCD PATENTS (ln)		-0.321
		(0.400)
PRE-1983 PLASMA PATENTS (ln)		1.275 *
		(0.549)
LATE TECH ENTRANT		2.887
		(1.902)
LCD VALUE RATING	-0.850	-1.042
	(0.693)	(0.761)
TV/COMPUTER EXPERIENCE	2.341	2.699 **
	(1.776)	(0.806)
INVERSE MILLS RATIO	3.010	2.978 *
	(3.789)	(1.395)
CATEGORY DESKTOP	0.202	-0.096
	(0.361)	(0.464)
CATEGORY TELEVISION	0.142	-0.183
	(0.791)	(0.767)
CONSTANT	-5.904	-8.043 ***
	(3.535)	(1.099)
R-Squared	0.152	0.437
n (Observations) / N (Firms)	39 / 18	39 / 18

SELECTION MODEL	Model 1	Model 2
PRE-1983 LCD *PLASMA PATENTS		-0.771
		(0.520)
PRE-1983 LCD PATENTS (ln)		3.240 *
		(1.474)
PRE-1983 PLASMA PATENTS (ln)		1.847
		(1.150)
LATE TECH ENTRANT		7.626 ^
		(4.566)
LCD VALUE RATING	1.180 *	1.475 *
	(0.509)	(0.610)
TV/COMPUTER EXPERIENCE	-2.026 **	-2.714 **
	(0.643)	(0.782)
JAPAN	-1.398	-6.589 **
	(1.068)	(2.350)
US/EU	-1.998 ^	-3.045 *
	(1.133)	(1.324)
CATEGORY DESKTOP	-0.697	-0.831
	(0.594)	(0.989)
CATEGORY TELEVISION	-0.552	-0.692
	(0.639)	(0.845)
CONSTANT	2.560 **	0.595
	(0.759)	(1.945)
R-Squared	0.294	0.453
n (Observations) / N (Firms)	93 / 55	93 / 55

^: p<0.10 *: p<0.05 **: p<0.01 ***: p<0.001

Standard errors listed in parentheses beneath coefficients

Table 5: Estimating relative effects of late commitment and early learning

	Prdct Value (Signif)	Prdct Value (Full)	Commit Late	Learn Early
Hedgers (Both Techs)	0.020	0.057	0.5	1.0
LCD Only	(0.535)	(0.535)	0.0	1.0
Plasma Only	0.555	0.555	1.0	1.0
Late Entrants	0.000	0.267	1.0	0.0