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THE EMERGENCE OF DOMINANT DESIGNS

Abstract

In many markets, technological evolution results in the emergence of a single product design that achieves market dominance. In this paper, we examine two questions: will a dominant design emerge in a new product category? If it does, how long will it be before a dominant design emerges? Thus, we simultaneously model the probability of emergence of a dominant design and the timing of that emergence, conditional on its emergence. Our model incorporates the effects of appropriability, network effects, size of the product’s value net, the standard setting process, radicalness of innovation and R&D intensity on the probability and the timing of dominant design emergence.

We use data for 63 office products and consumer durables to estimate a split population hazard model for the probability and timing of emergence of an initial dominant design. We find that a dominant design is more likely to emerge with weak appropriability of the rents associated with the product, with weak network effects, with low product radicalness and with high R&D intensity. Dominant designs that do emerge are likely to emerge sooner when there is weak appropriability, a large number of firms in the value net, standards are set by a de facto process, and low product radicalness. We also show that the model can be used to predict both the probability and the timing of the emergence of a dominant design in a new product category.

Keywords: dominant design, market evolution, technological evolution, split population model, network effects
INTRODUCTION

In many new or emerging product categories, the market accepts a particular product’s design architecture as one that defines the specifications for the entire product category; that design is referred to as the dominant design (Abernathy and Utterback 1978; Utterback 1994). The emergence of a dominant design in a new product category is an important event, significantly affecting firms’ strategies and their performance. A late emergence of a dominant design can retard market growth because potential customers delay purchasing the product waiting for a dominant design to emerge (Utterback 1994). A dominant design also shapes future generations of products in the category, resulting in “an architectural franchise” for the firm with a dominant design potentially locking out competitors (Schilling 1998). In this paper, we examine the probability and timing of emergence of an initial dominant design in a new product category.

There is considerable variation in the emergence of dominant designs across product categories. For example, the modern facsimile machine was introduced in 1960, but the dominant design, the GIII, did not emerge until 1983 (Baum, Korn and Kotha 1995). On the other hand, the dominant design for DVD (digital video disc) players emerged just three years after the product was introduced in 1996 (http: www.dvdforum.org). In other product categories, no dominant design has emerged even many years after product introduction, and it seems unlikely that a dominant design will ever appear. For example, the camcorder category, which saw its first product introduced in 1984, still supports multiple designs more than twenty years later. Those designs include the VHS (Home Video System), VHS-C (Home Video System-Compact), Super VHS, Super VHS-C, 8mm, Hi-8, and Digital 8 mm formats.
Dominant designs have been documented in diverse product categories, including video cassette recorders, nuclear reactors, automatically controlled machine tools and watches (Utterback 1994). The factors influencing the emergence of dominant designs have been identified primarily using conceptual models (Lee et al. 1995; Smith 1997), while empirical research has primarily focused on the ex-post performance implications of dominant designs (Christensen, Suárez, and Utterback 1998; Suárez and Utterback 1995).

The study of dominant designs is highly relevant for marketing managers whose strategies must be informed by marketplace dynamics. Competition before the emergence of a dominant design is between designs, whereas after its emergence, competition is within the more circumscribed domain of a dominant design. A dominant design not only influences the strategies and performance of firms that compete in the product category (e.g., DVD players), but affects firms in ancillary categories (e.g., movies and videogames for DVD players) as well.

In this paper, we examine the effects of product-market characteristics on the probability and the timing of the emergence of a dominant design. Specifically, we address two questions: First, what product-market characteristics influence whether a dominant design will emerge in a product category? And, second, conditional on the emergence of such a design, what product-market characteristics influence the timing of that emergence?

Consistent with past research (Christensen, Suárez and Utterback 1998), we take a market facing view of dominant design and define the time of emergence as when the market clearly favors one design over others. Unlike past research which has assumed that a dominant design will always emerge in a product category, our approach incorporates the possibility that a dominant design may never emerge.
We estimate a split-population hazard model (Schmidt and Witte 1989; Sinha and Chandrashekar 1992) of the probability and timing of emergence of a dominant design. That model allows for the possibility of two subpopulations of product categories: one in which a dominant design will emerge and another in which it will never emerge. We incorporate a number of product-market characteristics as predictors of the emergence of dominant designs and calibrate the model using data on 63 office products and consumer durables. The data are right-censored for 33 products where a dominant design had not yet emerged by 2003.

The results show that a dominant design is more likely to emerge with weak appropriability of rents associated with the product, weak network effects, low product radicalness, and high R&D intensity. Dominant designs that do emerge, emerge sooner when there is weak appropriability, a large number of firms in the value net, de facto standards and low product radicalness. The effects of the factors influencing the probability of the emergence of dominant design are different from their effects on its timing. The proposed model can be used as a predictive tool for estimating both the probability of emergence of a dominant design and the time of its emergence, given its product-market characteristics.

The paper is organized as follows. In the next two sections, we provide an overview of dominant designs, and then present the proposed model and hypotheses. We then describe the data, model estimation procedures, and results. We conclude by discussing the paper’s contributions, summarizing its limitations, and identifying directions for further research.

**DOMINANT DESIGNS: AN OVERVIEW**

The concept of a dominant design emerged from studies on industrial innovation in the 1970’s. In the early stages of market evolution, high market and technical uncertainty result in a diversity of product designs (Abernathy and Utterback 1978; Dosi 1982; Lee et al. 1995; Smith
At some point, one product’s design, i.e., the future dominant design, is favored by the market over other designs. A dominant design may not necessarily be one that embodies superior technical performance; sometimes it is a satisficing design in terms of technical possibilities driven by the accommodation of commercial interests between suppliers, users, and competitors (Tushman and Rosenkopf 1992; Wade 1995).

Evolutionary processes of variation, selection, and retention characterize product category evolution (e.g., Anderson and Tushman 1990; Tushman and Murmann 1998). Technological breakthroughs result in rivalry between alternative designs, resulting in a period of design variation or ferment. Viewed in this evolutionary perspective, the emergence of a dominant design is the transition point between the periods of variation and selection.

Empirical studies document the emergence of dominant designs in diverse product categories including typewriters, TVs, electronic calculators, automobiles (Utterback 1994), VCRs (Cusumano, Mylonadis and Rosenbloom 1992), cochlear implants (Van de Ven and Garud 1994), facsimile machines (Baum, Korn and Kotha 1995), cement, glass, and minicomputers (Anderson and Tushman 1990). The emergence of a dominant design affects firms’ market shares (e.g., Anderson and Tushman 1990) and survival (e.g., Baum, Korn and Kotha 1995; Christensen, Suárez and Utterback 1998; Suárez and Utterback 1995; Tegarden, Hatfield and Echols 1999).

However, dominant designs do not emerge in all product categories, as is seen with camcorders, supercomputers and videogame consoles (Frenken, Saviotti and Trommetter 1999). To our knowledge, past research has not examined why dominant designs emerge in some product categories but not others, a question we address in this paper.
Definition of Dominant Design

Table 1 summarizes the alternative definitions of dominant designs in the literature. From this table, we see that the definition of dominant designs has evolved from being broad and possibly tautological to one that is more specific. Here, we seek a definition of dominant design that is independent of its effects. Hence, following Christensen, Suaréz and Utterback (1998), we define a dominant design as the specification (consisting of a single, or a complement, of design features) that defines the product category’s architecture. We measure the time to a dominant design’s emergence as the time between the commercial introduction of the first product in the category and the time an alternative in the category, including the initial entrant, satisfies the definition above.

---- Insert Table 1 here ----

Dominant Designs versus Standards

Some past research (e.g., Anderson and Tushman 1990; Besen and Farrell 1994; Katz and Shapiro 1986; Schilling 1998) has equated ‘dominant designs’ with ‘standards’ using them interchangeably. Indeed, such terms as “standards wars” have been used to denote the battle between designs resulting in a dominant design (Shapiro and Varian 1999). In this paper, we draw a distinction between dominant designs and standards.

Following the convention used by engineering and numerous standards bodies, we use the term standards to denote the technical specifications for quality, reference, compatibility, adaptability, and connectivity which are required for the proper functioning of such products as fax machines, computers, and railway tracks (Grindley 1995; Krechmer 2000). Standards are inevitable requirements for products where there is interdependency between several components.
and/or between the users of the product because products must connect with each other directly (e.g., facsimile machines) or indirectly (e.g., personal computers), or require complementary goods to meet users’ needs (e.g., DVD players). Thus, standards in a product category serve a functional purpose, separate from market acceptance whereas, by definition, market acceptance is an integral aspect of a dominant design.

Two other aspects of dominant designs differentiate them from standards. First, a dominant design often emerges from competition between several designs. For example, in the home video recorder market, the VHS emerged as the dominant design as a result of competition between two video standards, Sony’s Betamax and JVC’s VHS. Second, dominant designs often consist of numerous standards. For example, the dominant design in the CD player category, the Philips-Sony design has over two dozen codified standards (http://www.philips.com).

To summarize, while there are product categories where dominant designs are equivalent to the standard in the product category (e.g., DVD in digital home video players), there are also categories with multiple standards and no dominant design (e.g., VHS, 8mm, mini-DVD etc. in camcorders).

A MODEL OF THE EMERGENCE AND TIMING OF A DOMINANT DESIGN

Technological evolution has long been viewed as if it were a random process, with a path-dependent trajectory that defies systematic modeling efforts (e.g., Ames and Rosenberg 1977; Arthur 1989; Rosenberg 1994). However, this view has been challenged by recent studies that model a product category’s evolution as a function of its product-market characteristics (Agarwal and Bayus 2002; Golder and Tellis 1997; 2004; Gupta, Jain and Sawhney 1999). In the spirit of this latter work, we suggest that a product category’s product-market characteristics
will affect its evolution, influencing both the probability and timing of the emergence of a dominant design in the category.

Integrating past research in technological evolution, we argue that the following product-market characteristics will affect whether and when a dominant design emerges in a product category: appropriability, network effects, the number of firms in the product’s value net, the type of standards setting process (*de jure* versus *de facto*), the radicalness of the product category, and the research and development intensity. We suggest that some product-market characteristics will affect both the probability and timing of a dominant design’s emergence, while other characteristics will affect either the probability or the timing. We next define these product-market characteristics and develop hypotheses of their effects on the probability and timing of the emergence of a dominant design.¹

**Appropriability**

Appropriability refers to aspects of the product category that govern firms’ ability to capture innovation rents in the product category (Levin et. al.1987; Teece 1986). Levin et. al. (1987) studied over 100 industries and concluded that appropriability is a multi-faceted construct embodying the following six aspects: patents to prevent duplication, patents to secure royalty income, secrecy of the new product development effort, lead time for development of the product, learning curve efficiency and sales and service effort that underlies the innovation. Appropriability for a product category may be represented along a continuum extending from a tight (closed) regime where firms are able to appropriate most or all innovation rents, to a weak (or open) regime where firms are able to appropriate little or no rents.

¹ The model also includes two control variables, the year of commercial product introduction and the presence of a recessionary environment during commercial introduction of the first product in the product category, for which we do not develop hypotheses but present the results subsequently.
Tight appropriability in a product category leads to disjointed competition and localized monopolies, with several independent, disconnected market niches reducing selection pressures crucial for the emergence of a dominant design (Anderson and Tushman 1990; Frenken, Saviotti and Trommetter 1999). With tight appropriability, product prices may also be higher because of limited industry-wide learning effects, lowering the probability of emergence of a dominant design (Levin et al. 1987). In such a situation, developers of complementary goods may not have the knowledge and incentives to develop complementary goods, reducing selection pressures delaying the emergence of a dominant design.

The potential advantages associated with a weak appropriability regime have gained prominence with the emergence of the open source movement in software development (Garud and Kumaraswamy 1993; Lecoq and Demil 2003; West 2003). Weak appropriability enables knowledge sharing between firms and the co-evolution of a network of cooperating competitors (Brandenberger and Nalebuff 1996). With weak appropriability, all firms in the network (or value net, as we call it) can share in the innovation rents. Such rent-sharing reduces firms' incentives to innovate independently of the future dominant design, increasing both the probability and hastening the emergence of a dominant design (Gallini 1985). For example, the emergence of the IBM PC as the dominant design in personal computers resulted, in part, because of its open architecture with extensive, public documentation (Khazam and Mowery 1994). Likewise, the emergence of the DVD format resulted because of the open format, and extensive, public documentation.

Integrating these arguments, we expect weak appropriability in a product category to increase selection pressures positively affecting both the probability of emergence and hastening the emergence of a dominant design. Hence,
\( H_{1e} \): The weaker the appropriability of the product category, the more probable the emergence of a dominant design.

\( H_{1t} \): The weaker the appropriability of the product category, the shorter the time to the emergence of a dominant design.

**Network Effects**

Positive network effects exist when a customer’s utility from a product increases as the number of customers who use the product (or compatible products) increases (Katz and Shapiro 1986). When the utility of a product to each user depends on the number of other users, the product exhibits direct network effects (e.g. facsimile machine, telephone). Indirect network effects arise when the link between consumer utility and the number of users in the network occurs through the increased availability of complementary products (e.g., movies on DVD’s for DVD players). An increase in the number of users of the focal hardware product increases the availability of complementary goods, in turn, increasing the utility that customers derive from the focal product.

Some aspects of strong network effects suggest that dominant designs are more likely to emerge and emerge early. For example, a dominant design in a product category with strong network effects assures potential adopters that a dominant design’s network will be the largest, resulting in further adoption of the future dominant design and establishing its market supremacy. Indeed, networked markets are typically “winner-take-all” so that a dominant design may have an early, large market share (Schilling 2002; Shapiro and Varian 1999). Such markets may tilt toward one product design, and do so rapidly because of strong selection pressures to choose a design early (e.g., Besen and Farrell 1994).

Other aspects of strong network effects suggest that dominant designs are less likely, and if they do emerge, emerge later. Prospective customers of products with direct network effects
may adopt a wait-and-see attitude, waiting for a dominant design to emerge, resulting in “excess inertia” which reduces the probability of emergence (Farrell and Saloner 1986; Goldenberg, Libai and Muller 2002). Such excess inertia may also exist in product categories with indirect network effects, where the lack of complementary goods may cause a “chicken-and-egg” coordination problem delaying a dominant design’s emergence (Gupta, Jain and Sawhney 1999). For example, in the HDTV market, Gupta, Jain and Sawhney (1999) find that complementors’ inactions played an important role in delaying the emergence of a dominant design. Srinivasan, Lilien and Rangaswamy (2004) report that the survival duration of a pioneer is negatively influenced by network effects, i.e., pioneers introducing products with stronger network effects survived for a shorter time than pioneers introducing products with weaker network effects, supporting the existence of excess inertia in product categories with network effects.

In sum, given the opposing effects of network effects, a priori, we do not hypothesize a directional effect of network effects on either the probability or the timing of emergence of a dominant design but observe it empirically. Thus,

\[ H_{2_e}: \text{The stronger the network effects in the product category, the less (or more) probable the emergence of a dominant design.} \]

\[ H_{2_t}: \text{The stronger the network effects in the product category, the longer (or shorter) the time to the emergence of a dominant design.} \]

**Value Net**

A firm’s linkages with external suppliers and producers of complementary products provide important sources of relational rents for the firm and utility for its customers (Dyer and Singh 1998). The value net of a product consists of suppliers and producers of complementary goods delivering utility, either directly or indirectly to the customer (Normann and Ramirez 1993; Stabell and Fjledstad 1998). Tushman and Rosenkopf (1992) and Wade (1995) suggest
that the interdependencies within a value net, or what they call a technological community, play a major role in the trajectory of technological evolution. Our interest here is whether the size of the value net affects the emergence of dominant design in the product category. We do not expect the value net of the product category to affect the probability of the emergence of a dominant design, but if a dominant design does emerge in a product category, we expect the product’s value net to affect the time to emergence of a dominant design.

The more firms in the value net, the greater the incentive for each firm to support a dominant design (if it emerges) because of higher resultant revenues (Amit and Zott 2002), thereby reducing the time to the emergence of a dominant design. Consider the DVD player: firms in the value net included the DVD player manufacturers (e.g., Matsushita, Sony and Philips), film studio houses (e.g., Paramount and Disney), film producers (e.g., Dreamworks, Pixar), movie rental chains (e.g., Blockbuster and Hollywood Video) and media manufacturers (e.g., Memorex and TDK). A dominant design permits the firms in the value net to suspend further investments in product development efforts, to compete within the dominant design and to achieve both supply-side and demand-side efficiencies (Utterback 1994). As a result, as the number of firms in the value net increases, the greater the revenue generation in the value net, providing both the financial and institutional pressure to establish a dominant design quickly (Wade 1995).

However, the more firms in the value net, the greater the agency costs (e.g., transaction and coordination costs) for the various firms in the value net, which could potentially delay a dominant design’s emergence (Bergen, Dutta and Walker 1992). While we acknowledge this latter, opposing effect, we expect that the incentives for rent generation and sharing will dominate the potential higher transaction costs. Hence,
**H₃**: The greater the number of firms in the value net of the product category, the shorter the time to the emergence of a dominant design.

**Standards Setting Process**

A review of the history of standards setting processes suggests this process may be broadly classified into two types: *de facto* and *de jure* standards setting (Besen and Farrell 1994; David and Greenstein 1990; Farrell and Saloner 1988; 1992). In a *de facto* standards setting process, standards for the product category are set by market forces. The operating system for personal computer is an example of a product category that initially had several *de facto* standards (e.g., CP/M, MS-DOS). In a *de jure* standards-setting process, standards are established through a formal process by standards organizations which may include independent bodies such as the International Telecommunications Union (ITU), The Institute of Electric and Electronic Engineers (IEEE), or government bodies like the National Institute of Standards and Technology (NIST). We do not expect the standards setting process to affect the probability of the emergence of a dominant design but do expect the process to affect the time to emergence of a dominant design, if it emerges.

*De jure* standards-setting processes, which typically include manufacturers, suppliers and complementors, exclude end-users and tend to support current or known technologies over emergent or new ones (Sirbu and Zwimpfer 1985). Because there are many member participants in the standards organization with potentially conflicting interests, consensus is harder to achieve, delaying the emergence of a dominant design (David and Greenstein 1990). The facsimile machine standard was set through a *de jure* standards setting by the several members of the CCITT (Consultative Committee for International Telegraph and Telephone) located in several different countries, and required 23 years until the emergence of a dominant design.
De facto standard setting processes, in contrast, are characterized by aggressive market competition without intervention by standards bodies. In addition, possible unilateral control of de facto standards by one firm, whose design may likely be the future dominant design, may alleviate consumer uncertainty about a possible war of attrition between standards, hastening the emergence of a dominant design (Shapiro and Varian 1999). Consistent with these arguments, Farrell and Saloner (1988) use a theoretical model to show that de facto standards setting processes are faster than de jure processes. Thus, we expect a de facto standards setting process (relative to de jure) in a product category to hasten the emergence of a dominant design. Thus,

\[ H_4: \text{Compared to a de jure standards setting process, a de facto standards setting process in a product category will result in a shorter time to the emergence of a dominant design.} \]

Radicalness

Radical products (e.g., instant photography, microwave ovens) involve new technologies representing both significant advances in technology and significant consumer benefits (Chandy and Tellis 2000). Radical products offer a low initial performance-price ratio and face limited market acceptance (Christensen 1997; Utterback 1994). The evolution of radical products is characterized by high uncertainty and numerous product variants are developed to identify viable technological trajectories and consumer preferences (Sorenson 2000). Not surprisingly, a radical product is refined by several firms in sequential iterations of product development into a “market-ready” form (Basalla 1988). The limited market acceptance for the rudimentary versions of the radical product may dampen the selection pressures for a dominant design’s emergence makes it less likely to emerge (Tushman and Murmann 1998). For example, the microwave oven, which Raytheon developed in 1946 and Tappan commercialized in 1955, was a radical innovation which faced poor market acceptance. Over time, independent efforts by several
American and Japanese firms over twenty years were necessary before development of market-worthy designs.

The evolution of a radical innovation occurs over several years and often involves the sequential development of several technology platforms (Rosenberg 1994). The development of these variants, each with different marketplace support, leads to local, idiosyncratic market niches with independent product development efforts, thus delaying the emergence of a dominant design. Hence, we expect a negative effect of radicalness on the probability of the emergence of a dominant design and a positive effect on its timing.

\[ H_{5e}: \text{The greater the radicalness of the product category, the less probable the emergence of a dominant design.} \]

\[ H_{5t}: \text{The greater the radicalness of the product category, the longer the time to the emergence of a dominant design.} \]

**R&D Intensity**

Product categories differ in their extent of research and development (R&D) intensity, i.e., the depth and breadth of knowledge required to design and commercialize a product (John, Weiss and Dutta 1999). In R&D intensive product categories, extensive integration of interdisciplinary technologies across diverse firms may be necessary to achieve technology fusion critical for product development in such product categories (Iansiti and West 1997). Thus, a dominant design can provide a clear pathway in what would otherwise be a noisy and confusing technological environment.

R&D intensive product categories are characterized by a high level of knowledge spillover, not only across firms in the industry, but also across related industries (Tsai 2005). Knowledge spillovers in such product categories spur advances in multiple market niches,
increasing product diversity, which, in turn, creates the variation crucial for the emergence of a dominant design (Wilson, Weiss and John 1990). Moreover, product categories with higher R & D intensity also experience frequent technological changes, resulting in technological rivalries between alternative designs (Adam, Trajtenberg and Fogarty 2000; Lotz 1998), thus increasing the selection pressures for the emergence of a dominant design. Thus,

$H_{0e}$: The greater the R&D intensity of the product category, the more likely the emergence of a dominant design.

Table 2 summarizes the hypotheses for the probability and the timing for the emergence of a dominant design.

---- Insert Table 2 here ----

**METHOD**

**Split Population Hazard Model**

To allow for the possibility that a dominant design may never emerge, we use a split-population hazard model, which segments the population into two subpopulations, one that will eventually experience the event of interest (here, the emergence of dominant design) and one that will never experience it. The model generates two sets of simultaneously estimated coefficients, one for the probability of the event ever occurring and the other for the timing of the event, conditional on its occurrence. The split population approach has been typically applied to problems of criminal recidivism (e.g., Schmidt and Witte 1989). In marketing, Sinha and Chandrashekaran (1992) used a split-population model of the determinants of innovativeness of banks, allowing some banks to be eventual non-adopters of technology and showed that that the model performed better than a standard hazard model that assumes that all banks would eventually adopt the technology.
We develop the model as follows. Let $N$ be the number of product categories, and the period of observation be $[0, \tau]$. Let $C_i$ be an indicator to denote whether or not a dominant design occurred in $(0, \tau)$ for the $i$th product category. If $C_i=1$, the observation is treated as complete, if $C_i=0$, the observation is censored. For each category, we observe the following data: the duration $t_i$ for the completed observations, i.e., for products for which a dominant design occurred in the interval $[0, \tau]$ and the vector $X_i$ of covariates for all $N$ product categories.

**Censoring.** Our data is characterized by Type 1 censoring (right censoring). Each product category has a fixed censoring time $\tau > 0$ such that $t_i$ is observed if $t_i \leq \tau$; otherwise we know only that $t_i > \tau$. Then, $C_i=1$ if $t_i \leq \tau$ and $C_i=0$ if $t_i > \tau$ and $t_i = \min(t_i, \tau)$. The likelihood function for a Type I censored sample is based on the probability distribution of $(\delta_i, t_i)$, $i=1,2,..n$ where $\delta_i$ is the probability of the emergence of dominant design. For our analysis, $\delta_i$ is a function of several independent variables, i.e., $\delta_i = \delta(X_i)$. For the completed observations where $t_i \leq \tau$, $P(C_i=1, t_i = t_i) = f(t_i)$. For the censored observations, $t_i > \tau$,

$$P(C_i=0) = P(t_i > \tau \mid X_i) = 1 - F(\tau) = S(\tau).$$

See Lawless (2003), pp. 52-53 and pp. 543-555 for details.

**Likelihood Function.** Let $A = \{ \ldots, a_i, \ldots \}$ be an unobservable vector, where $A_i=1$ if the $i$th product category will witness the emergence of a dominant design, and $A_i=0$, if the $i$th product category will never witness the emergence of a dominant design. We specify the probability of a dominant design emergence as: $\delta(X_i) = P(A_i=1) = 1/[1 + \exp(\alpha X_i)]$ and $P(A_i=0) = 1 - \delta(X_i)$, so that the set of product categories are “split” into two groups—one where a dominant design will eventually emerge and the other in which it will never emerge. Note that $0 \leq \delta(X_i) \leq 1$. Then the log-likelihood for the $N$ independent product categories is
\[ LL = \sum_{i=1}^{N} \{C_i \ln[f(t_i)] + (1 - C_i) \ln[S(\tau)]\}. \] (1)

For the product category in which a dominant design emerged \((C_i=1)\), we observe the time at which it emerged and also the set of time-invariant covariates \(X_i\) associated with the category. In addition, for these categories, \(A_i=1\). For the product categories in which a dominant design does not emerge during the observation period \((C_i=0)\), we also observe the product-market characteristics, \(X_i\). In addition, for these categories, either a dominant design will never occur in the future, in which case \(A_i=0\), or a dominant design will eventually emerge, but will emerge beyond the period of observation, in which case, \(A_i=1\) and \(t > \tau\).

Let \(F=F(t_i|X_i, A_i=1)\) be the cumulative distribution function for the emergence of a dominant design for those product categories for which a dominant design will eventually emerge, \(f(t_i|X_i, A_i=1)\) be the corresponding probability density and \(S=(1-F(.))\) be the survival function. For the product categories where a dominant design emerges during the observation period, we have

\[ P(C_i = 1, t = t_i) = P(A_i = 1) f(t_i | X_i, A_i = 1) = \delta(X_i) f(t_i | X_i, A_i = 1) \] (2)

and for the censored observations, we get:

\[ P(C_i = 0) = P(A_i = 0) + P(A_i = 1) P(t_i > \tau | A_i = 1) \] so that

\[ P(C_i = 0) = 1 - \delta(X_i) + \delta(X_i)[1 - F(\tau | X_i, A_i = 1)] = 1 - \delta(X_i) + \delta(X_i)S(\tau) \] (4)

The log-likelihood function is then given by:

\[ LL = \sum_{i=1}^{N} \{C_i \ln[\delta(X_i) f(t_i | X_i, A_i = 1)] + (1 - C_i) \ln[1 - \delta(X_i) + \delta(X_i)S(\tau)]\} \] (5)
Thus, the split hazard model captures observed heterogeneity in both the probability of the eventual emergence of a dominant design ($\delta(X_i)$) and the timing of its emergence, $f(t_i|X_i, A_i=1)$ as a function of the covariates. For censored observations, it also incorporates unobserved heterogeneity in the form of two unobserved groups of products, one of which will witness the emergence of a dominant design and the other will not.

**Estimation.** To estimate the parameters for the effects of the covariates on the probability and the timing of the emergence of a dominant design, we use the Accelerated Failure Time (AFT) specification of the hazard model exploring alternative distribution functions $f(.)$ for the base hazard. This approach using parametric estimation of the base hazard overcomes potential problems of identification that can occur with the use of the proportional hazard specification of split-hazard models (Kuk and Chen 1992). Standard asymptotic results for maximum likelihood estimation apply. We implement the model using the Survival procedure in LIMDEP.

**Data**

We identified two broad product categories, office products and consumer durables where there is considerable variance in the explanatory variables. These two categories have been studied in past research on market evolution (e.g., Agarwal and Bayus 2002; Golder and Tellis 1997; 2004). We limit our focus to product categories that emerged after World War II, because the postwar period witnessed the emergence of new technologies (e.g., computing, electronics, and telecommunications) that are different in scope and character from earlier technologies (e.g., mechanical, and electro-mechanical) (Teitelman 1994).

We used the historical method to collect data on some variables and merged that data with expert ratings obtained for the other variables (Golder 2000). For each product category, we obtained information about the historical evolution of the category from articles published in
scholarly journals, company histories and online business databases. Where possible, we used multiple sources, including industry experts to increase the reliability of our data. We were able to collect reliable information for 63 product categories whose introductions span over 50 years (see Appendix A). The sample size of 63 product categories compare favorably with those used in recent studies in marketing (Chandy and Tellis 2000; Golder and Tellis 1997; 2004). All the data are from public sources.

Measures

Given our interest in developing a cross-product category model of the emergence of dominant designs covering product categories where there are no objective measures for some product characteristics (i.e., appropriability, network effects, value net and radicalness), we used raters to develop retrospective measures of explanatory variables that can apply equally to all product categories under study. Where feasible, we validated the subjective measures with objective data obtained from secondary sources. We next discuss how we developed the various measures.

Emergence and timing of dominant designs. In the early stages of product evolution before the emergence of a dominant design, there are several technological changes in the product category (Christensen, Suaréz, and Utterback 1998; Sanderson and Uzumeri 1990). After a dominant design emerges, competition in the product category moves from competition between alternative product designs to competition within the dominant design, with the competing products using a dominant design’s key features, and focusing on process innovations. Guided by these distinctive characteristics surrounding the emergence of a dominant design, technology strategy researchers (Christensen, Suaréz, and Utterback 1998)
have retrospectively identified when one design achieves market acceptance over other competing designs. We use this method to identify the emergence of dominant designs.

Using product literature and product reviews from archival sources (e.g., Consumer Reports, trade magazines, and Computing magazines), three graduate students constructed case histories of each product category's evolution (see Appendix B provides brief histories of two such categories). We then used two other graduate students to independently identify if and when a dominant design emerged. Following the convention for survival models (Lawless 2003) we need two variables to model survival data. The first denotes whether or not a dominant design emerged in the product category. If a dominant design emerged, then the dominant design variable is coded as 1. If a single design specification was not favored by the market and did not define the product category, but several designs are observed (e.g., videogame consoles, camcorders), this variable is coded as 0. Dominant designs were observed in 30 product categories in the study. The data are right-censored at 2003 for the 33 product categories in which a dominant design had not yet emerged in 2003 (i.e., it is not clear if a dominant design will ever emerge in these categories, only that it had not emerged by 2003). We defined the second variable as the number of years between the time the product category was introduced and the emergence of a dominant design. For the timing measure, there were discrepancies between the two raters for three of the 30 product categories in which a dominant design was identified. We resolved these discrepancies using a reassessment of multiple industry sources and inputs to the raters from the authors (Golder 2000).

Given its centrality in our study, we used two checks of our measure of dominant design to assess its reliability. First, we used eleven industry experts to verify from them the year of emergence of a dominant design obtained from archival sources. The experts included five
editors of trade journals (Disk Drive Report, Computer Reseller News, Future Image Report etc.), two representatives of industry organizations (Consumer Electronics Association, DVD Forum), and four executives from industry including market research organizations (e.g., Gartner Group, IDC). In most cases (26 of the 30 product categories where a dominant design emerged), there was unanimous agreement between the student raters and the industry experts. In four product categories (facsimile machine, floppy drive, mainframe computer and microprocessor chip) the dates for the emergence differed by at most two years. The student raters, the authors and the industry experts jointly consulted and reconciled the dates for these four cases.

Second, we validated the measure and timing of dominant design with an objective measure of its market share performance. We obtained archival measures of market share for the dominant design in the product category (cf. Anderson and Tushman 1990) which we are able to collect for 24 products of the 30 products in which a dominant design emerged. Following Anderson and Tushman (1990), we coded the year in which the design’s market share exceeded 50% for four consecutive years. Our dominant design’s timing ratings measure correlates highly (\( \rho = 0.864 \)) with the time to achieve the 50% market share threshold for these 24 products.\(^2\) Thus, we are reassured about the reliability of the measure of the emergence and timing of dominant design that we use in this paper.

**Appropriability.** Levin et al. (1987) conceptualize the appropriability of a product as the protection of competitive R&D advantages in the product category, encompassing the following six aspects: 1) patents (or copyrights) to prevent duplication, 2) patents (or copyrights) to secure royalties, 3) secrecy of the new product development effort, 4) lead time for the development of the new product, 5) speed in moving down the learning curve in new product development, and

\(^2\) We thank a reviewer for this suggestion.
6) sales and service support. Because the sixth aspect is not related to product innovation, we excluded this aspect of appropriability from our measure.

We used two groups of expert raters to measure the appropriability of the product categories: (1) Academic experts: six professors at three business schools who are recognized experts on organizational innovation, on high technology products or on network effects; and (2) Industry experts: two sets of industry experts, one from the computer industry and another from the consumer electronics product group. Following Levin et al. (1987), we asked raters to rate the products (1 to 7 scale) on each of the five mechanisms of protecting the competitive advantages of R&D efforts in the product category. To obtain the measure of appropriability, we added the ratings given on each aspect of appropriability by each rater for each category, and averaged the ratings separately for the two groups of raters. The higher a product category’s rating on the appropriability scale, the weaker its appropriability.

Network effects. Following Srinivasan, Lilien and Rangaswamy (2004), we used raters to measure a product’s network effects as a continuous, two-dimensional variable, representing both direct and indirect effects. Again, we used two groups of raters (different from the raters of appropriability) to measure the degree of network effects: (1) Academic experts: four professors at two business schools who are recognized experts on organizational innovation, on high technology products or on network effects; and (2) MBA students: a class of 25 MBA students with an average experience of three years in the high tech industry. We asked the raters to separately rate the degree of direct and indirect network effects associated with each product category on a 1 (no network effects) to 7 (very strong network effects) scale. We computed the extent of network effects for each product category from each rater by adding the scores for direct and indirect network effects and averaging separately for each group of raters.
**Radicalness.** We used Chandy and Tellis’ (2000) radicalness scale, which has two dimensions: (1) whether a new product incorporates a substantially different core technology (technology radicalness) on a scale from 1 to 9, and (2) whether a new product provides substantially higher customer benefits relative to existing products (benefits radicalness) on a scale from 1 to 9 and developed a radicalness measure by adding the two scores. Six academics who were experts in organizational innovation and ten graduate engineering students provided the radicalness ratings corresponding to the time of each product’s introduction. We provided each rater a brief description of each product category, including the timeline of the product introduction, and details of the previous generation product. To obtain the measure of radicalness, we added the ratings by each rater for technology and benefits radicalness and averaged the ratings separately for the two groups of raters.

**Number of firms in the value net.** Three graduate students who prepared detailed case histories of the 63 products gathered details on the value net of the product category, the sources of network effects, and complementary and compatible products (Amit and Zott 2001). One of the authors guided the students in the method to identify and develop the value net of product. Two other graduate students (different from those who identified the dominant design) counted the number of firms in the value net. There was complete agreement between the two raters for 57 products (91% of the cases). The counts for the remaining six products were resolved by a discussion between the raters and the authors.

**Standards setting process.** The two graduate student raters (those who counted the number of firms in the value net) also independently identified whether the standards setting process was *de facto* (coded as 1) or *de jure* (coded 0). There was unanimous agreement between
the student raters on the standards setting process. The nature of the standards setting process was reconfirmed with three academic experts who had worked in the innovation area.

*R & D intensity.* Consistent with past research (Agarwal and Bayus 2002), we measured R & D intensity using the average R & D expenditure as a percentage of sales between 1987-1997 for each product category in the study at the three-digit SIC level.³

*Recession at time of product introduction.* We measured the recessionary environment using a categorical variable based on whether there was a recession in the U.S. economy in the year of product introduction, defined as two consecutive quarters of a decline in real Gross Domestic Product.

*Reliability of scale ratings from raters.* For each product characteristic for which we used raters, we had multiple raters rate all the products (McGraw and Wong 1996; Shrout and Fleiss 1979). We computed the inter-rater reliability, which measures homogeneity of the ratings to establish the extent of consensus across the various raters using the intra-class (i.e. inter-judge) correlations. The intra-class reliability coefficient for the ratings provided by each rater for a given target measures the proportion of variance that is attributable to the target. See McGraw and Wong 1996 for more details on the statistics involved in inter-rater reliability coefficients. To ensure internal consistency, we eliminated raters with item-to-total correlations below 0.40 for appropriability, network effects and radicalness respectively. The retained experts had intra-class reliability ratings of 0.85, 0.82, 0.87 and the graduate students had intra-class reliability ratings of 0.74, 0.76, and 0.77 for appropriability, network effects, and radicalness of the product respectively, indicating acceptable internal consistency. The average ratings from the two groups

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were highly correlated at 0.75, 0.82, and 0.80 respectively for appropriability, network effects, and radicalness of the product. We report results using the ratings from the academic experts, but also test for the robustness of the results using other raters, as we report subsequently.

RESULTS

Descriptive Statistics

In 33 (52 %) of the 63 product categories, no dominant design had emerged by 2003 and the average time to emergence of a dominant design for the remaining 30 product categories where a dominant design emerged was 6.500 years. Table 3 contains the descriptive statistics and correlation matrix of the variables. The correlations are within acceptable limits (highest correlation = 0.498 between standard setting process and research and development intensity). Following Belsley, Kuh and Welsch (1980), we assessed the threat from multicollinearity. The VIF’s (Variance Inflation Factor) were much lower than 10 (average = 1.470; maximum = 1.903) suggesting that multicollinearity is not a threat to the validity of the study’s findings.

---- Insert Table 3 ----

Model Selection

We are interested in determining whether the base hazard rate is constant, increasing, or decreasing with time. We estimated the model in equation (5) using three distribution functions, Lognormal, Log-logistic, and Weibull that accommodate a changing hazard rate. While the general pattern of results is similar across the models, the model estimated with the Log-logistic function fits best. We report the results for that model in Table 4 (Column 1). The parameters of the log-logistic function (λ= 0.227; σ = 0.293) suggest that the hazard function is mound shaped, increasing for the first 6 years and then decreasing.
We first discuss the effects of the control variables. The year of product introduction has no effect on the probability of emergence (b = -4.276, ns) or the timing of emergence of a dominant design (b = 14.630, ns) whereas the presence of a recessionary environment (b = 0.653, p < 0.01) delays the emergence of a dominant design. The results generally support the hypotheses. With respect to the probability of emergence of a dominant design in a product category, as hypothesized in H1e, we find that appropriability has a negative effect (b = -1.202, p < 0.01), suggesting that the weaker the appropriability, the more likely the emergence of a dominant design. And as hypothesized in H6e, the greater the R&D intensity, the more likely the emergence of a dominant design, although we get only marginal significance for this result (b = -0.694, p < 0.10). On the other hand, as hypothesized in H2e, and H5e respectively, network effects (b = 0.547, p < 0.05) and radicalness (b = 1.362, p < 0.01) negatively affect the probability of emergence of a dominant design.

With respect to timing, as hypothesized in H1t, H3t, and H4t respectively, weak appropriability (b = -0.167, p < 0.01), the number of firms in the value net of the product (b = -0.314, p < 0.01) and de facto standards setting process (b = -0.876, p < 0.01) hasten the emergence of a dominant design. And, as hypothesized in H5t, radicalness (b = 0.325, p < 0.01) delays the emergence of a dominant design. We find no support for H2t for the effect of network effects on the timing of the emergence of a dominant design (b = 0.048, ns).

We then performed two model comparisons to examine the explanatory power of the split population hazard model. First, we compared the split population hazard model with all the

\[4\] Because of the logistic formulation for the probability of emergence of the dominant design, a negative coefficient denotes a higher probability of emergence.
explanatory variables for both the probability and timing of emergence, with a model that did not include covariates. A likelihood ratio test of the difference between the model with no explanatory variables and the complete model ($\chi^2 = 53.982$, degrees of freedom [df] = 12, $p < 0.01$) indicates that the split hazard log-logistic model with the explanatory variables offers a significant improvement in accounting for the variance in the data. Next, we compared the hypothesized model with a single population model (i.e., incorporating only timing and shown in column 2 of Table 4). The proposed complete model rejects the single population model ($\chi^2 = 44.354$, df = 5, $p < 0.01$). In addition, the parameter estimates change sign and only appropriability has a significant, although opposite, effect in the single population model. Such changes in sign may be expected when a single population model is a misspecification of an underlying split population (Sinha and Chandrashekaran 1992).

**Robustness Tests**

*Robustness of model specification.* We performed additional analyses to examine the robustness of the model specification. First we examined the effect of stepwise addition of variables to our models (results not reported here). For both the probability and the timing models, the coefficients are consistent in terms of their signs in the stepwise models with those we report in Table 4, reconfirming that multicollinearity does not appear to be a threat to the validity of the our findings. Second, we included two additional control variables (both were dummy variables): whether the candidate designs in the product category had a dominant firm sponsor at the time of introduction and whether the candidate designs in the product category were backward-compatible with a previous generation product as judged by two graduate student raters. The analysis indicated that these two variables affected neither the probability nor the
timing of the emergence of a dominant design, supporting the robustness of the model specification.\(^5\)

**Censoring date.** As discussed earlier, the censoring mechanism here is Type 1, for which the maximum likelihood estimation of the hazard function provides consistent estimates (see Lawless 2003). To explore whether the results are sensitive to sampling variations due to using 2003 as the censoring date, we re-estimated the model with alternative censoring dates: 2002, 2001, 2000, 1999 and 1998. We get consistent results although, as may be expected, the significance levels of the parameter estimates vary across the different censoring dates. We report the results for the censoring dates of 2002 and 1998 in columns 3 and 4 of Table 4.

**Sample.** Although the sample size compares well with past research, it is small and, therefore, we performed a bootstrap analysis to examine the sensitivity of the results to sampling variations (Efron 1979). The bootstrapping analysis (Column 5 of Table 4) indicate that the results are robust to sampling variations.

**Ratings source.** To cross-validate the estimation results from the ratings of appropriability, network effects and radicalness from academic raters, we re-estimated the model using ratings obtained from student raters (network effects, radicalness) and industry experts (appropriability) and found results consistent with those reported in Table 4.

**Direct and indirect network effects.** We also separately examined the impact of direct and indirect network effects on the probability and timing of emergence of a dominant design (not reported here). The hypothesized model (BIC value = 141.421) outperforms the disaggregated network effects model (BIC = 146.229). In the disaggregated model, direct network effects has a weak effect (\(p < 0.01\)) on the probability and timing of emergence of a dominant design.

\(^5\) We thank a reviewer for this suggestion.
dominant design, while indirect network effects has no effect on either. We conjecture that a possible reason for the lack of support for the individual effects of direct and indirect network effects on the emergence of dominant design may be because both direct and indirect network effects coexist ($\rho = 0.245, p < 0.01$), and jointly determine the dynamics of dominant design emergence. The disaggregated effect of direct and indirect network effects on firm and market outcomes is an area for future empirical research.\(^6\)

**Predictive Validity**

We performed two predictive validity tests to assess the model’s ability to predict the probability and the duration of the emergence of a dominant design.

*Probability of emergence of dominant design.* Because the data are right-censored at 2003, a product category in which a dominant design is not observed during the observation period may either, 1) never witness the emergence of a dominant design, or 2) may witness the emergence of a dominant design after 2003, the date of right censoring. To examine the predictive validity of the probability of emergence of a dominant design, we selected products introduced in or before 1984 ($n=42$) as the sample for predicting the probability of emergence of dominant design. The cutoff date of 1984 provides twenty years after product introduction, three standard deviations beyond the average time for observed dominant design emergence. Hence, we can reasonably assume that a dominant design is unlikely to emerge in these product categories.

Using this approach, the split population log-logistic hazard model predicts (1) emergence of dominant design for 16 categories, 14 of which had witnessed the emergence of a dominant design by 2003, (2) no emergence of a dominant design for 26 categories, of which 18

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\(^6\) We thank a reviewer for this suggestion.
have not witnessed the emergence of a dominant design resulting in a false-positive rate of 14% and a false negative rate of 31%. Using the criterion advocated by Morrison (1969) for evaluating the predictive performance of discriminant analysis models, the overall proportion of correct classification is 0.762, which compares favorably with the proportional chance, $C_{pro}$ of 0.530 where $C_{pro} = [\alpha]^2 + [1 - \alpha]^2$, where $\alpha$ is the proportion of categories for which a dominant design has actually emerged and $[1 - \alpha]$ is the proportion for which a dominant design has not emerged. A Chi-square test of misclassification indicates that the proposed split hazard model predicts dominant design emergence well ($\chi^2 = 12.780$, df = 1, $p < 0.01$). We obtain generally similar results in the predictions of the emergence of a dominant design when we use alternative cutoff years of 1981 ($\chi^2 = 13.464$, df = 1, $p < 0.01$) and 1987 ($\chi^2 = 10.792$, df = 1, $p < 0.01$).

*Timing of emergence of dominant design.* To evaluate the ability of the model to predict timing of a dominant design, we apply jackknifing, using data of the 30 products for which a dominant design was observed. We hold out one target product, re-estimate the model on the other 29 products, and then use the estimated parameters to predict the emergence of a dominant design for the remaining products (Golder and Tellis 1997).

We compute the mean absolute deviation (MAD), defined as $
_{i=1}^n |D_{ia} - D_{ip}|$
where $D_{ia}$, $D_{ip}$, and $n$ denote the actual time to emergence of dominant design for product $i$, the predicted time of emergence of dominant design for product $i$, and the number of products (n=30) respectively. The MAD using the predicted model is 2.714 years compared to a MAD of 3.571 years without the model, an improvement of 24%. A post-hoc examination of absolute deviations indicated that, elimination of two products (color television and audio cassette player), reduces the MAD for the predicted model to 2.184 years compared to a MAD of 3.806 years without the model, an improvement of 43%. The small sample size precludes the determination
of why these two products have such high leverage on model performance. Overall, the results of the predictive validity tests demonstrate that the proposed split population hazard model predicts both the probability and the timing of the emergence of a dominant design quite well.

DISCUSSION

We investigated the likely emergence and the timing of the emergence of a dominant design in a product category as a function of its product-market characteristics. Our model allows for the possibility that a dominant design may never emerge in some product categories. The model specifies the effects of product-market characteristics both on the probability of the emergence of a dominant design in a product category and on the timing of the emergence of a dominant design, conditional on its emergence.

Theoretical Contributions

The paper’s findings contribute to the literature in marketing that explores product evolution. Our results suggest that a split population model that allows for the non-emergence of a dominant design in some product categories adequately captures the factors influencing the emergence of dominant designs, especially when compared to a single-population hazard model. From a methodological perspective, the split population model can be extended to other product evolution processes such as product takeoff, to account for the possibility that some products may never take off (e.g., Sony minidisk and quadraphonic sound).

The results of the split population model indicate that dominant designs may never emerge in some product categories, a result that runs counter to an implicit assumption in the existing literature that a dominant design will eventually emerge in all categories. A product category’s characteristics differentially influence the probability and timing of emergence of a
dominant design. The facilitating role of weak appropriability on both the probability and the
timing of emergence of a dominant design suggest that appropriability has opposing effects on
firms’ quest for securing rents from innovations (Teece 1986). On the one hand, weak
appropriability (e.g., lack of patent protection, short lead time etc.) results in loss of rents
because other firms can imitate the innovator’s design. On the other hand, weak appropriability
is associated with a greater probability of emergence, and the earlier emergence of dominant
design, increasing the rents for all firms in the market. The negative effect of network effects on
the probability of emergence of a dominant design reinforces recent empirical research (e.g.,
Goldenberg, Libai and Muller 2002; Srinivasan, Lilien and Rangaswamy 2004) that suggests
that, for office products and consumer durables, the excess inertia of network effects appears to
outweigh its installed base effects.

The negative effect of the number of firms in the value net on the time to emergence of a
dominant design suggests that if there are more firms appropriating rents in a product category, a
dominant design is likely to emerge sooner. These findings are somewhat counter to other
evidence on the negative transaction and coordination costs of inter-organizational relationships.
For the product categories in this study, the added rents from the value net appear to outweigh
the added transaction costs, thereby speeding the emergence of a dominant design.

Likewise, the findings indicate that a dominant design is likely to emerge sooner in
product categories where the standards setting process is *de facto* (as compared to *de jure*). This
is consistent with prior theoretical work in economics (Farrell and Saloner 1988; Sirbu and
Zwimpfer 1985), and points to the efficiency of market mechanisms in forcing a quicker
emergence of a dominant design.
Dominant designs are less likely to occur, and if they occur, take longer to emerge, for more radical product categories. However, our results for R&D intensity suggest that dominant designs are more likely to occur in more R&D intensive categories, with the higher investments in the product categories perhaps providing necessary variation facilitating the selection process and hastening the emergence of a dominant design.

**Managerial Contributions**

Our empirical findings have some clear implications for managers. First, our results suggest that managers should understand that a dominant design may never emerge in many product categories, especially those with tight appropriability, strong network effects, and high product radicalness. Some of these characteristics are strategic decision variables. For example, weak appropriability significantly influences both the emergence and the timing of a dominant design. In addition, market-based *de facto* standard setting processes (relative to *de jure* standard setting processes) appear to be efficient for the timely emergence of dominant designs. Managers who wish to increase the probability of their product becoming a dominant design, and/or speed up the emergence of dominant designs may consider employing strategies to weaken appropriability strategies and encourage *de facto* standard setting processes. The decision of IBM and Intel to share know-how for blade servers indicates a strategic attempt to speed up the emergence of a dominant design centered on their technologies and a *de facto* standard setting process (Wall Street Journal, September 2, 2004).

Second, the model can be used to predict the probability and timing of emergence of dominant designs, given a set of product-market characteristics. These predictions can be useful to managers in the ex-ante planning of marketing strategies. For example, of the products that have not yet seen dominant designs emerge, the product category with the highest probability is
satellite radio with $P(\text{emergence}=0.86)$ and the least likely is microwave oven with $P(\text{emergence}=0.02)$. It will be interesting to see if these predictions from our model turn out to be accurate.

**Limitations and Future Research**

This study has some limitations that present opportunities for further research. We primarily focused only on the time to emergence of the initial dominant design in a new product category. Some researchers (e.g., Anderson and Tushman 1990; Tushman and Anderson 1986) have conceptualized the emergence of dominant designs as a sequence of technological discontinuities resulting in several dominant designs. Indeed, in some product categories (e.g., operating systems for personal computers, spreadsheet software), the initial dominant design was replaced by a subsequent design. To extend the findings from this study, future research could address the emergence of multiple, sequential dominant designs perhaps through repeated-events, split population hazard modeling approach.7

Given our interest in developing a cross-product category model where consistent objective measures of many variables were not available, we had to develop retrospective subjective measures and rely on raters to obtain data for many of those measures. With improved record keeping, future researchers could use measures not subject to the possible hindsight biases of our subjective measures. Alternatively, researchers could consider focusing in-depth on specific product categories (e.g., Shankar and Bayus 2003) which would enable the use of objective measures within the product category. Better records would also help in assessing the performance implications of dominant designs for each member of the value net. The extent of fragmentation in the value net may also influence the emergence of the dominant

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7 We thank two reviewers for this suggestion.
design, which we are unable to examine, given our data, is also an important area for future research.

The emergence of dominant design may also be influenced by the strategic actions of firms. For example, factors influencing the emergence of a dominant design may include the firms’ collateral assets (Teece 1986) and strategic maneuvering by firms (Cusumano, Mylonadis and Rosenbloom 1992). Future research on the emergence of dominant design incorporating strategic firm factors should provide further useful insights.

On net, however, we hope that we have contributed in some distinct way to a basic understanding of the whether and when questions about the emergence of dominant designs and that our approach and modeling framework will be helpful for managers seeking to reduce uncertainty about the dynamics and evolution of such markets.
<table>
<thead>
<tr>
<th>Author(s) (year)</th>
<th>Definition of dominant design</th>
<th>Empirical method to identify dominant design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abernathy and Utterback (1975); Abernathy (1978)</td>
<td>A dominant design is a single architecture that establishes dominance in a product category.</td>
<td>Conceptual paper</td>
</tr>
<tr>
<td>Anderson and Tushman (1990)</td>
<td>A dominant design is a single architecture that establishes dominance in a product category.</td>
<td>A design as dominant if it acquires more than 50% market share of the product category and maintained it for four years in a row.</td>
</tr>
<tr>
<td>Utterback (1994)</td>
<td>The dominant design in a product category is the one that wins the allegiance of the marketplace, the one that competitors and innovators must adhere to if they hope to command significant market following. A dominant design is a product in a product category that gains general acceptance as the standard on technical features, and that other market players must follow if they wish to acquire significant market share.</td>
<td>No details provided.</td>
</tr>
<tr>
<td>Suaréz and Utterback (1995)</td>
<td>The dominant design is a specific path along an industry’s design hierarchy which establishes dominance among competing design paths.</td>
<td>Industry experts used to classify dominant designs in typewriter, automobile, television, picture tube, transistor and electronic calculator.</td>
</tr>
<tr>
<td>Christensen, Suaréz and Utterback (1998)</td>
<td>A dominant design emerges in a product category when one product’s design specifications (consisting of a single or a complement of design features) define the product category’s architecture.</td>
<td>Industry experts used to identify the emergence of the dominant design in the rigid disk drive industry based on the technical elements of the product category evolution over time.</td>
</tr>
</tbody>
</table>
Table 2
Summary of Hypotheses and Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Probability of Emergence of Dominant Design</th>
<th>Timing of Emergence of Dominant Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriability</td>
<td>$H_{1e}$: The weaker the appropriability of the product category, the more probable the emergence of a dominant design. (supported)</td>
<td>$H_{1t}$: The weaker the appropriability of the product category, the shorter the time to the emergence of a dominant design. (supported)</td>
</tr>
<tr>
<td>Network effects</td>
<td>$H_{2e}$: The stronger the network effect in the product category, the less (more) probable the emergence of a dominant design. (less likely supported)</td>
<td>$H_{2t}$: The stronger the network effect in the product category, the longer (shorter) the time to the emergence of a dominant design. (not supported)</td>
</tr>
<tr>
<td>Value net</td>
<td>-</td>
<td>$H_{3t}$: The greater the number of firms in the value net of the product category, the shorter the time to the emergence of a dominant design. (supported)</td>
</tr>
<tr>
<td>Standards setting process</td>
<td>-</td>
<td>$H_{4t}$: Compared to a <em>de jure</em> standard setting process, a <em>de facto</em> standards setting process in a product category will result in a shorter time to the emergence of a dominant design. (supported)</td>
</tr>
<tr>
<td>Radicalness of innovation</td>
<td>$H_{5e}$: The greater the radicalness of the product category, the less probable the emergence of a dominant design. (supported)</td>
<td>$H_{5t}$: The greater the radicalness of the product category, the longer the time to the emergence of a dominant design. (supported)</td>
</tr>
<tr>
<td>Research and development intensity</td>
<td>$H_{6e}$: The greater the R &amp; D intensity of the product category, the more probable the emergence of a dominant design. (supported)</td>
<td>-</td>
</tr>
<tr>
<td>Variable</td>
<td>Range of Variable</td>
<td>Mean (standard deviation)</td>
</tr>
<tr>
<td>----------</td>
<td>------------------</td>
<td>---------------------------</td>
</tr>
</tbody>
</table>
| 1. Time to Emergence of Dominant Design (n=30) | 2-20 | 6.500 (4.944) | -
| 2. Appropriability | 5-35 | 16.567 (7.896) | 1.000 |
| 3. Network effects | 2-14 | 8.532 (3.160) | -0.482** | 1.000 |
| 4. Number of firms in the value net | 1-5 | 2.206 (1.095) | -0.104 | 0.435*** | 1.000 |
| 5. Standard setting process | 0-1 | 54 – de facto 85% | -0.026 | -0.238* | 0.018 | 1.000 |
| 6. Radicalness | 2-18 | 11.967 (2.071) | 0.070 | -0.054 | -0.029 | -0.081 | 1.000 |
| 7. Research and development intensity | 1.670-9.000 | 7.398 (2.755) | -0.010 | -0.174 | 0.216* | 0.498*** | 0.155 | 1.000 |

# correlations with the left-censored duration variable are not meaningful and therefore not reported.

*p < 0.10, ** p < 0.05 and *** p < 0.01
Table 4
Split Population Model for Emergence of Dominant Design

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hypothesized Model</th>
<th>Single Population Duration Model</th>
<th>Cutoff year = 2002</th>
<th>Cutoff year = 1998</th>
<th>Bootstrapping</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Probability of Emergence</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>21.557 (808.56) (ns)</td>
<td>21.370 (810.843)</td>
<td>23.649 (808.56) (ns)</td>
<td>21.478 (804.381) (ns)</td>
<td></td>
</tr>
<tr>
<td>Appropriability ($H_{le}$)</td>
<td>-1.202 (0.469)***</td>
<td>-1.199 (0.468)***</td>
<td>-1.108 (0.533)**</td>
<td>-1.190 (0.462)***</td>
<td></td>
</tr>
<tr>
<td>Network effects ($H_{sle}$)</td>
<td>0.547 (0.243)**</td>
<td>0.548 (0.247)**</td>
<td>0.545 (0.263)**</td>
<td>0.541 (0.243)**</td>
<td></td>
</tr>
<tr>
<td>Radicallness ($H_{re}$)</td>
<td>1.362 (0.512)***</td>
<td>1.359 (0.519)***</td>
<td>1.282 (0.621)**</td>
<td>1.348 (0.511)***</td>
<td></td>
</tr>
<tr>
<td>Research and development intensity ($H_{de}$)</td>
<td>-0.694 (0.418)*</td>
<td>-0.698 (0.421)*</td>
<td>-0.695 (0.448)</td>
<td>-0.686 (0.408)*</td>
<td></td>
</tr>
<tr>
<td>Year of product introduction</td>
<td>-4.276 (105.612) (ns)</td>
<td>-4.243 (106.298) (ns)</td>
<td>-4.456 (129.922) (ns)</td>
<td>-4.251 (105.459) (ns)</td>
<td></td>
</tr>
<tr>
<td><strong>Timing of Emergence</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-112.067 (157.163) (ns)</td>
<td>19.919 (292.345) (ns)</td>
<td>-75.955 (166.122) (ns)</td>
<td>-90.338 (112.456) (ns)</td>
<td>-111.955 (157.133) (ns)</td>
</tr>
<tr>
<td>Appropriability ($H_{1t}$)</td>
<td>-0.167 (0.062)***</td>
<td>0.265 (0.130)**</td>
<td>-0.136 (0.065)**</td>
<td>-0.159 (0.062)***</td>
<td></td>
</tr>
<tr>
<td>Network effects ($H_{2t}$)</td>
<td>0.048 (0.091) (ns)</td>
<td>-0.126 (0.106) (ns)</td>
<td>0.049 (0.105) (ns)</td>
<td>0.058 (0.071) (ns)</td>
<td></td>
</tr>
<tr>
<td>Number of firms in the value net ($H_{3t}$)</td>
<td>-0.314 (0.119)***</td>
<td>-0.220 (0.190)</td>
<td>-0.307 (0.144)**</td>
<td>-0.308 (0.119)***</td>
<td></td>
</tr>
<tr>
<td>Standards setting process ($H_{4t}$)</td>
<td>-0.876 (0.230)***</td>
<td>-0.054 (0.472) (ns)</td>
<td>-0.927 (0.246)***</td>
<td>-0.867 (0.210)***</td>
<td></td>
</tr>
<tr>
<td>Radicallness ($H_{5t}$)</td>
<td>0.325 (0.069)***</td>
<td>0.310 (0.071)***</td>
<td>0.245 (0.086)***</td>
<td>0.283 (0.049)***</td>
<td></td>
</tr>
<tr>
<td>Year of product introduction</td>
<td>14.630 (20.582) (ns)</td>
<td>-2.039 (38.473) (ns)</td>
<td>9.891 (21.749) (ns)</td>
<td>5.329 (24.757) (ns)</td>
<td>7.721 (0.134) (ns)</td>
</tr>
<tr>
<td>Recession during product introduction</td>
<td>0.653 (0.211)***</td>
<td>0.146 (0.451) (ns)</td>
<td>0.524 (0.234)***</td>
<td>0.603 (0.197)***</td>
<td></td>
</tr>
<tr>
<td>$\sigma$ of log logistic distribution</td>
<td>0.293</td>
<td>0.744</td>
<td>0.289</td>
<td>0.288</td>
<td>0.293</td>
</tr>
<tr>
<td>Log-likelihood</td>
<td>-43.780</td>
<td>-65.957</td>
<td>-42.960</td>
<td>-38.903</td>
<td>-43.743</td>
</tr>
<tr>
<td>Average predicted probability of emergence ($\delta$)</td>
<td>0.600</td>
<td>0.602</td>
<td>0.602</td>
<td>0.602</td>
<td>0.610</td>
</tr>
</tbody>
</table>

* denotes parameter estimates and standard errors in parentheses. *p < 0.10, ** p < 0.05 and *** p < 0.01
APPENDIX A

Product Categories in the Study (n=63)

<table>
<thead>
<tr>
<th>No.</th>
<th>Product Category</th>
<th>Year of Product Introduction</th>
<th>Time to Emergence of Dominant Design</th>
<th>Dominant Design Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>3.5&quot; floppy drive</td>
<td>1979</td>
<td>1984</td>
<td>Sony’s design</td>
</tr>
<tr>
<td>2.</td>
<td>AM stereo</td>
<td>1982</td>
<td>1986</td>
<td>Motorola’s C-Quam System</td>
</tr>
<tr>
<td>3.</td>
<td>Answering Machine</td>
<td>1962</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4.</td>
<td>Anti-virus software</td>
<td>1982</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5.</td>
<td>Audio cassette player</td>
<td>1962</td>
<td>1969</td>
<td>Philips’ design</td>
</tr>
<tr>
<td>6.</td>
<td>Automatic teller machine</td>
<td>1967</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7.</td>
<td>Cable modem</td>
<td>1995</td>
<td>1998</td>
<td>DOCSIS specifications</td>
</tr>
<tr>
<td>8.</td>
<td>CAD software</td>
<td>1982</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9.</td>
<td>Camcorder</td>
<td>1984</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10.</td>
<td>Camera phone</td>
<td>2000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11.</td>
<td>CD player</td>
<td>1982</td>
<td>1985</td>
<td>Philips-Sony’s design</td>
</tr>
<tr>
<td>12.</td>
<td>CD-ROM drive</td>
<td>1983</td>
<td>1986</td>
<td>Sony’s design</td>
</tr>
<tr>
<td>13.</td>
<td>Cellular phone</td>
<td>1979</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14.</td>
<td>Color television</td>
<td>1951</td>
<td>1957</td>
<td>(NTSC)</td>
</tr>
<tr>
<td>15.</td>
<td>Cordless phone</td>
<td>1975</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17.</td>
<td>Desk top publishing software</td>
<td>1984</td>
<td>1987</td>
<td>Adobe Pagemaker</td>
</tr>
<tr>
<td>18.</td>
<td>Dial-up modem 56 K</td>
<td>1979</td>
<td>1998</td>
<td>56KFlex</td>
</tr>
<tr>
<td>19.</td>
<td>Digital camera</td>
<td>1991</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20.</td>
<td>Dot matrix printer</td>
<td>1964</td>
<td>1968</td>
<td>ESC/P from Epson</td>
</tr>
<tr>
<td>21.</td>
<td>DSL modem</td>
<td>1996</td>
<td>1999</td>
<td>G.Lite</td>
</tr>
<tr>
<td>22.</td>
<td>DVD player</td>
<td>1996</td>
<td>1999</td>
<td>DVD design from Zenith</td>
</tr>
<tr>
<td>23.</td>
<td>Electric toothbrush</td>
<td>1960</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24.</td>
<td>Fax machine</td>
<td>1960</td>
<td>1983</td>
<td>GIII</td>
</tr>
<tr>
<td>25.</td>
<td>File zipping software</td>
<td>1986</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>26.</td>
<td>Flash memory</td>
<td>1988</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>27.</td>
<td>Flat bed scanners</td>
<td>1978</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>28.</td>
<td>Food processor</td>
<td>1972</td>
<td>-</td>
<td>-</td>
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<tr>
<td>30.</td>
<td>HDTV</td>
<td>1987</td>
<td>1993</td>
<td>Standard Definition Television</td>
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<tr>
<td>31.</td>
<td>Home microwave oven</td>
<td>1955</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>32.</td>
<td>Inkjet printer</td>
<td>1984</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>33.</td>
<td>Instant messenger</td>
<td>1998</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>34.</td>
<td>Instant photography</td>
<td>1948</td>
<td>1955</td>
<td>Polaroid</td>
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<tr>
<td>No.</td>
<td>Product Category</td>
<td>Year of Product Introduction</td>
<td>Time of Emergence of DD</td>
<td>Dominant Design Specifications</td>
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<td>------------------------------</td>
<td>------------------------------</td>
<td>-------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>35.</td>
<td>Internet Service providers</td>
<td>1980</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>36.</td>
<td>Internet telephony</td>
<td>1997</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>37.</td>
<td>Laser printer</td>
<td>1984</td>
<td>-</td>
<td>-</td>
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<tr>
<td>38.</td>
<td>Main frame computer</td>
<td>1946</td>
<td>1964</td>
<td>IBM 360</td>
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<tr>
<td>40.</td>
<td>Mini audio disc</td>
<td>1992</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>41.</td>
<td>Notebook computer</td>
<td>1980</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>42.</td>
<td>OCR software</td>
<td>1974</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>43.</td>
<td>Operating system for PCs</td>
<td>1977</td>
<td>1984</td>
<td>MS DOS</td>
</tr>
<tr>
<td>44.</td>
<td>Pager</td>
<td>1974</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>45.</td>
<td>Personal computer</td>
<td>1975</td>
<td>1983</td>
<td>IBM PC</td>
</tr>
<tr>
<td>46.</td>
<td>Personal digital assistant</td>
<td>1993</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>47.</td>
<td>Personal finance software</td>
<td>1983</td>
<td>1987</td>
<td>Intuit</td>
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<tr>
<td>48.</td>
<td>Photocopiers</td>
<td>1950</td>
<td>1959</td>
<td>Xerox 914</td>
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<tr>
<td>49.</td>
<td>Pocket calculator</td>
<td>1971</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>50.</td>
<td>Portable file document software</td>
<td>1993</td>
<td>1999</td>
<td>Adobe PDF</td>
</tr>
<tr>
<td>52.</td>
<td>Projection TV</td>
<td>1973</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>53.</td>
<td>Satellite radio</td>
<td>1998</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>54.</td>
<td>Single-use camera</td>
<td>1986</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>55.</td>
<td>Spreadsheet software</td>
<td>1979</td>
<td>1984</td>
<td>Lotus 1-2-3</td>
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<tr>
<td>56.</td>
<td>Super audio CDs</td>
<td>1999</td>
<td>-</td>
<td>-</td>
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<tr>
<td>57.</td>
<td>Video game console</td>
<td>1971</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>58.</td>
<td>Home video recorders</td>
<td>1975</td>
<td>1978</td>
<td>JVC VHS</td>
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<td>59.</td>
<td>Web camera</td>
<td>1991</td>
<td>-</td>
<td>-</td>
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<tr>
<td>60.</td>
<td>Web server software</td>
<td>1995</td>
<td>-</td>
<td>-</td>
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<tr>
<td>61.</td>
<td>Word processing software</td>
<td>1979</td>
<td>1983</td>
<td>Wordstar</td>
</tr>
<tr>
<td>62.</td>
<td>Work station</td>
<td>1980</td>
<td>1986</td>
<td>Sun’s Unix</td>
</tr>
<tr>
<td>63.</td>
<td>Zip drives</td>
<td>1995</td>
<td>1997</td>
<td>Iomega</td>
</tr>
</tbody>
</table>
APPENDIX B

Brief Histories of Two Product Categories

Camcorder (Dominant design did not emerge)\(^8\)

In January 1982, several leading consumer electronics firms announced a universal standard for camcorders, the “8mm video” format. In March 1983, 127 video-related companies agreed on standards to ensure compatibility of all 8mm camcorders. Ten months later, Eastman Kodak Company introduced the world’s first 8mm camcorder in January 1984, followed by Sony in Fall 1984.

In January 1985, several Japanese firms including Canon, Fuji, Pioneer Electronic, Kyocera, Aiwa, Sanyo and Ricoh licensed Sony’s 8mm camcorder technology. In February 1985, Japanese Victor Company (JVC) launched a rival VHS camcorder format, compatible with its VHS home video recorders but incompatible with Sony’s 8 mm camcorders. JVC’s VHS-C format got a big boost when several firms including Matsushita, Toshiba, Hitachi, Mitsubishi, Philips and Sharp licensed the VHS-C technology from JVC.

In the period between 1985 and 1990, both the 8mm and the VHS-C formats enjoyed fluctuating popularity in the market with neither format gaining market dominance. In addition, several other camcorder formats including Super VHS, Super VHS-C, and Digital 8 mm were introduced in the early 1990s, each of which acquired niche market positions. Given these sequence of events, a dominant design did not emerge in the camcorder market at that time or since then, despite several firms having agreed on a standard two years before the commercial introduction of camcorders.

Digital Video Player (Dominant design emerged)

Seeking to avoid the VHS-Betamax “format war” of the 1970s, in the mid-1990s, consumer electronics manufacturers led by Sony, Toshiba, and Panasonic, in conjunction with movie studios led by Warner and Columbia (a division of Sony) worked together in the DVD consortium (http://www.dvdforum.org). The objective of the DVD consortium was to establish the DVD standard as an open format. In addition, the DVD discs were encoded with the Dolby Digital sound process to be compatible with virtually all home theater electronics. The DVD format for digital video players was not unchallenged.

In September 1997, Circuit City introduced a competing format called the Digital Video Express (DIVX) which was partially compatible with DVD. DIVX players would play all DVD discs, but DVD players could not play DIVX discs, priced on par with DVD discs. Early adopters did not know it, but at the time of the DIVX announcement, Circuit City had neither the hardware nor the software for product demonstration.

When Circuit City finally launched DIVX in the fall of 1998, it faced an uphill battle as studio support for DIVX never materialized. By May 1999, nearly two million DVD players had been shipped to retailers, compared to about 165,000 for DIVX. At the same time, there were 3,317 DVD movie titles available on the DVD format while only 471 titles available on the DIVX format. In June 1999, Circuit City withdrew DIVX from the market and the DVD format emerged as the dominant design.

\(^8\) We thank a reviewer for the suggestion to include the case histories.
REFERENCES


