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The Emergence of Dominant Designs

In many product categories, technological evolution results in the emergence of a single product design that achieves market dominance. In this article, the authors examine two questions: Will a dominant design emerge in a new product category? and If it does, how long will it be before a dominant design emerges? Thus, the authors simultaneously model the probability of emergence of a dominant design and the time of that emergence, conditional on its emergence. The model incorporates the effects of several product-market characteristics on the probability and time of dominant design emergence, including appropriability of the rents associated with the product, network effects, size of the product's value net, the standards-setting process, radicalness of innovation, and research-and-development intensity. The authors use data for 63 office products and consumer durables to estimate a split-population hazard model for the probability and time of emergence of the dominant design. They find that a dominant design is more likely to emerge with weak appropriability, weak network effects, low product radicalness, and high research-and-development intensity. Dominant designs that emerge are likely to emerge sooner in product categories in which there is weak appropriability, there are a large number of firms in the value net, the standards are set by a de facto process, and there is low product radicalness The proposed model can be used to predict both the probability and the time of the emergence of a dominant design in a new product category.

In many new product categories, the market accepts a particular product's design architecture as one that defines the specifications for the entire product category; such a design is referred to as the dominant design (Abernathy and Utterback 1978; Utterback 1994). The emergence of a dominant design in a product category is an important event that significantly affects firms' strategies and performance. The late emergence of a dominant design can retard market growth because potential customers delay purchasing the product and wait 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 and potentially locking out competitors (Schilling 1998). In this article, we examine the probability and time of emergence of a dominant design in a new product category.

There is considerable variation in the emergence of dominant designs across product categories. For example, the modern fax machine was introduced in 1960, but the dominant design, the GIII, did not emerge until 1983 (Baum, Korn, and Kotha 1995). Conversely, the dominant design for DVD players emerged just three years after product introduction in 1996. In other product categories, a dominant design has not emerged many years after product introduction, and it seems unlikely that a dominant design will ever materialize. For example, the camcorder category, introduced in 1984, supports multiple designs more than 20 years later. These designs include the VHS (home video system), VHS-C (home video system–compact), super VHS, super VHS-C, 8 mm, Hi-8, and digital 8 mm formats.

Dominant designs have been documented in diverse product categories, including VCRs, nuclear reactors, automatically controlled machine tools, and watches (Utterback 1994). The factors that influence the emergence of dominant designs have been identified with conceptual models (Lee et al. 1995; Smith 1997; Suaréz 2004), whereas empirical research has focused primarily on the *ex post* performance implications of dominant designs (Christensen, Suaréz, and Utterback 1998; Suaréz 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 in the product category (e.g., DVD players) but also affects firms in ancillary categories (e.g., movies and video games for DVD players).

In this article, we examine the effects of product-market characteristics on the probability and time of the emergence of a dominant design. We address two questions: First, what

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product-market characteristics influence whether a dominant design will emerge in a product category? Second, conditional on the emergence of a dominant design, what product-market characteristics influence the time of that emergence?

Consistent with prior research (Christensen, Suaréz, and Utterback 1998), we take a market-facing view and define the time of the dominant design's emergence as when the market clearly favors one design over others. Unlike prior research, which has implicitly assumed that a dominant design will always emerge, our approach incorporates the possibility that a dominant design may sometimes never emerge.

We estimate a split-population hazard model (Schmidt and Witte 1989; Sinha and Chandrashekaran 1992) of the probability and time of emergence of a dominant design, which allows for two subpopulations of product categories: one in which a dominant design will emerge and one in which it will never emerge. We incorporate 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 for which 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 research-and-development (R&D) intensity. Dominant designs that emerge do so sooner when there is weak appropriability, a large number of firms in the value net, de facto standards, and low product radicalness. The same factor may influence both the dominant design's probability and its time of emergence, but in different ways. The proposed model can be used as a predictive tool to estimate both the probability of emergence of a dominant design and the time of its emergence, given a set of product-market characteristics.

We organize the article as follows: In the next two sections, we provide an overview of dominant designs and present the proposed model and hypotheses. We then describe the data, the model estimation procedures, and the results. We conclude by discussing the article'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 1970s. In the early stages of market evolution, high market and technical uncertainty results in a diversity of product designs (Abernathy and Utterback 1978; Dosi 1982; Lee et al. 1995; Smith 1997; Utterback 1994). At some point, the market favors one product's design (i.e., the future dominant design) over the other designs. A dominant design may not necessarily be the one that embodies superior technical performance; sometimes, it is a satisficing design in terms of technical possibilities driven by the accommodation of commercial interests among 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 create a 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, televisions, electronic calculators, automobiles (Utterback 1994), VCRs (Cusumano, Mylonadis, and Rosenbloom 1992), cochlear implants (Van de Ven and Garud 1994), fax 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, Suaréz, and Utterback 1998; Suaréz and Utterback 1995; Tegarden, Hatfield, and Echols 1999).

However, dominant designs do not emerge in all product categories (e.g., camcorders, supercomputers, video game consoles). To our knowledge, prior research has not examined why dominant designs emerge in some product categories but not in others. Thus, we address the question in this article.

Definition of Dominant Designs

Over the years, the definition of dominant designs has evolved from being broad and possibly tautological (i.e., being defined by its effects) to being more specific. Table 1 summarizes alternative definitions of dominant designs in the literature. In this article, we seek a definition of a dominant design that is independent of its effects. Following the work of Christensen, Suaréz, and Utterback (1998), we define a dominant design as the specification (consisting of a single design feature 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 introduction of the first product in the category and the time an alternative in the category satisfies our definition.

Dominant Designs Versus Standards

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

Following the convention used in the engineering discipline and by numerous standards bodies, we use the term "standards" to denote the technical specifications for quality, reference, compatibility, adaptability, and connectivity that are required for the proper functioning of products, such as fax machines, computers, and railway tracks (Grindley 1995; Krechmer 2000). Standards are an

TABLE 1
Alternative Definitions of a Dominant Design in the Extant Literature

Source	Definition of a Dominant Design	Empirical Method to Identify a Dominant Design
Abernathy and Utterback (1978)	A dominant design is a single architecture that establishes dominance in a product category.	Conceptual paper.
Anderson and Tushman (1990)	A dominant design is a single architecture that establishes dominance in a product category.	A design is dominant if it acquires more than 50% market share of the product category and maintains it for four consecutive years.
Utterback (1994)	The dominant design in a product category is the one that wins the allegiance of the marketplace; it is 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 that other market players must follow if they wish to acquire significant market share.	No details provided.
Suaréz and Utterback (1995)	The dominant design is a specific path along an industry's design hierarchy that establishes dominance among competing design paths.	Industry experts were used to classify dominant designs in typewriters, automobiles, televisions, picture tubes, transistors, and electronic calculators.
Christensen, Suaréz, and Utterback (1998)	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.	Industry experts were 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.

inevitable requirement for these products because of interdependency among several components or among the products' users because these products must either connect with one another directly (e.g., fax machines) or indirectly (e.g., personal computers [PCs]) or require complementary goods to meet users' needs (e.g., DVD players). Thus, standards in a product category serve a functional purpose that is independent of 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 among 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 Japanese Victor Company's (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 more than two dozen codified standards.

To summarize, although there are product categories in which 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., for camcorders, there are VHS, 8 mm, mini-DVD, and so forth).

A Model of the Probability and Time of Emergence 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 (e.g., Ames and Rosenberg 1977; Rosenberg 1994). However, this view has been challenged by studies that model a product category's evolution as a function of its product-market characteristics (Agarwal and Bayus 2002; Golder and Tellis 1997; Gupta, Jain, and Sawhney 1999). In the spirit of this latter work, we suggest that a product category's product-market characteristics affect its evolution, influencing both the probability and the time of the emergence of a dominant design.

Extending previous research, we argue that the following product-market characteristics affect whether and when a dominant design emerges in a product category: appropriability, network effects, the number of firms in its value net, the type of standards-setting process (de jure versus de facto), its radicalness, and its R&D intensity. We suggest that some product-market characteristics affect both the probability and the time of a dominant design's emergence, whereas others affect only the probability or the time of emergence. Next, we define these product-market characteristics and develop hypotheses of their effects on the probability and time of emergence of a dominant design.[1]

Appropriability

Appropriability refers to aspects of the product category that govern firms' abilities to capture innovation rents in the product category (Levin et al. 1987; Teece 1986). Levin and colleagues (1987) studied more than 100 industries and concluded that appropriability is a multifaceted construct that embodies 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 can be represented along a continuum that extends from a tight (closed) regime, in which firms can appropriate most or all innovation rents, to a weak (open) regime, in which firms can appropriate little or no rents.

Tight appropriability leads to disjointed competition and localized monopolies with several independent, disconnected market niches that reduce the selection pressures that are 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 industrywide 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 or the incentives to develop complementary goods, reducing selection pressures and delaying the emergence of a dominant design.

The 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; Lecocq and Demil 2002; West 2003). Weak appropriability enables knowledge sharing among firms and the coevolution of networks of cooperating competitors (Brandenberger and Nalebuff 1996). With weak appropriability, all firms in the network, or the "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, both increasing the probability of the emergence of a dominant design and hastening the time to emergence (Gallini 1985). For example, the emergence of the IBM PC as the dominant design in PCs resulted, in part, because of its open architecture with extensive public documentation (Khazam and Mowery 1994). Likewise, the emergence of the DVD format resulted, in part, because of the open format and extensive public documentation.

Integrating these arguments, we expect that weak appropriability in a product category increases selection pressures and positively affects both the probability of the emergence of a dominant design and the time of the emergence. Thus, we expect the events "emergence" (e) and "time of emergence" (t) to be conditionally dependent, given appropriability.

> H_{1e}: The weaker the appropriability of the product category, the more probable is the emergence of a dominant design.
>
> H_{1t}: The weaker the appropriability of the product category, the shorter is 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., fax 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 for DVD players). An increase in the number of users of the focal hardware product increases the availability of complementary goods, which in turn increases 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 the dominant design's network will be the largest, resulting in its further adoption and ultimately establishing its market supremacy. 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 design and do so rapidly because of 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, they emerge later. Prospective customers of products with direct network effects may adopt a "wait-and-see" attitude, 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 in which the lack of complementary goods may cause a "chicken-and-egg" coordination problem that delays the emergence of a dominant design (Gupta, Jain, and Sawhney 1999). For example, in the HDTV market, Gupta, Jain, and Sawhney (1999) find that complementors' inactions delayed 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 that introduce products with stronger network effects have shorter survival duration than pioneers that introduce products with weaker network effects), supporting the existence of excess inertia in product categories with network effects. 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 time of

[1]The model also includes two control variables—the year of first product introduction and the presence of a recessionary environment during first product introduction—for which we do not develop hypotheses but present the results subsequently.

emergence of a dominant design; rather, we observe it empirically.

H_{2e}: The stronger (weaker) the network effects in the product category, the less (more) probable is the emergence of a dominant design.

H_{2t}: The stronger (weaker) the network effects in the product category, the longer (shorter) is the time to the emergence of a dominant design.

Value Net

A firm's linkages with its suppliers and producers of complementary products are important sources of relational rents for the firm and utility for its customers (Dyer and Singh 1998). The product's value net consists of suppliers and producers of complementary goods that deliver utility either directly or indirectly to the customer (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 is whether and how the size of the value net affects the emergence of a dominant design in a product category.

Because the value net typically consists of firms with different, frequently competing objectives, firms may initially prefer different designs, and thus we do not expect the value net of a product category to have the cohesion necessary to create selection pressures to affect the probability of the emergence of a dominant design; however, if the emergence of a dominant design seems inevitable, we expect the product's value net to affect the time to emergence, as we describe subsequently.

The more firms that are in the value net, the greater is the incentive for each firm to support a dominant design (if it emerges) because of higher resultant revenues (Amit and Zott 2001), thus 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, Philips), film studios (e.g., Paramount, Disney), film producers (e.g., Dreamworks, Pixar), movie rental chains (e.g., Blockbuster, Hollywood Video), and media manufacturers (e.g., Memorex, TDK). A dominant design permits firms in the value net to suspend further investments in product development, to compete within the dominant design, and to achieve supply-side and demand-side efficiencies (Utterback 1994). As a result, as the number of firms in the value net increases, the greater is the revenue generation in the value net, providing the financial and institutional pressure to establish a dominant design quickly (Wade 1995).

However, the more firms that are in the value net, the greater is the agency costs (e.g., transaction and coordination costs) for various firms in the value net, which could potentially delay a dominant design's emergence (Bergen, Dutta, and Walker 1992). Although we acknowledge this latter, opposing effect, we expect that the incentives for rent generation and sharing dominate the potential higher transaction costs.

H_{3t}: The greater the number of firms that are in the value net of the product category, the shorter is the time to the emergence of a dominant design.

Note that according to our hypothesis, we expect the events of emergence and time of emergence to be conditionally independent, given the value net of the product category.

Standards-Setting Process

A review of the standards-setting process suggests that this process can be broadly classified into two types: de jure and de facto standards setting (Besen and Farrell 1994; David and Greenstein 1990; Farrell and Saloner 1988, 1992). In a de jure standards-setting process, standards are established through formal processes by standards organizations, which may include independent bodies, such as the International Telecommunications Union and the Institute of Electric and Electronic Engineers, or government bodies, such as the National Institute of Standards and Technology. In a de facto standards-setting process, standards for the product category are set by market forces. The operating system for PCs is an example of a product category that initially had several de facto standards (e.g., CP/M, MS-DOS). Because standards-setting processes, regardless of whether they are de jure or de facto, involve considerable uncertainty (e.g., compatibility, connectivity) among several firms with frequently competing interests, we do not expect the standards-setting process to affect the probability of the emergence of a dominant design, but we expect it to affect the time to the 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, it is more difficult to achieve consensus, delaying the emergence of a dominant design (David and Greenstein 1990). The fax machine standard was set through a de jure standards-setting process by several members of the Consultative Committee for International Telegraph and Telephone located in several different countries, and it required 23 years for the emergence of a dominant design.

In contrast, de facto standards-setting processes are characterized by aggressive market competition without intervention by standards bodies. Possible unilateral control of de facto standards by one firm, whose design may likely be the future dominant design, could also alleviate consumer uncertainty about a war of attrition between standards and shorten the time to the emergence of a dominant design (Shapiro and Varian 1999). Consistent with these arguments, Farrell and Saloner (1988) find that de facto standards-setting processes are faster than de jure processes.

H_{4t}: Compared with a de jure standards-setting process, a de facto standards-setting process in a product category results in a shorter time to the emergence of a dominant design.

Radicalness

Radical products (e.g., instant photography, microwave ovens) involve new technologies that offer significant advances in both technology and consumer benefits (Chandy and Tellis 2000). Radical products, which offer a low initial performance-to-price ratio, 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 into a "market-ready" form (Basalla 1988). The limited market acceptance for rudimentary versions of the radical product may dampen selection pressures for a dominant design's emergence, thus making 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 product that faced poor initial market acceptance. Independent development efforts by several U.S. and Japanese firms over 20 years were necessary before the introduction of market-worthy designs.

The evolution of a radical product occurs over several years and involves the sequential development of several technology platforms (Rosenberg 1994). The development of 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. Thus, we expect a negative effect of radicalness on the probability of the emergence of a dominant design and a positive effect on its time of emergence.

> H_{5e}: The greater the radicalness of the product category, the less probable is the emergence of a dominant design.
>
> H_{5t}: The greater the radicalness of the product category, the longer is the time to the emergence of a dominant design.

R&D Intensity

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

Product categories that are R&D intensive are characterized by high levels of knowledge spillovers, not only across firms in the category but also across related categories (Tsai 2005). Knowledge spillovers in such product categories spur advances in multiple market niches, increasing product diversity, which in turn creates the variation that is 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 rivalries between alternative designs (Adam, Trajtenberg, and Fogarty 2000; Lotz 1998), which increases the selection pressures for the emergence of a dominant design. However, given the noisy and confusing technology environment in R&D-intensive product categories that persist even as the dominant design emerges, we do not expect R&D intensity to affect the time of emergence of the dominant design.

> H_{6e}: The greater the R&D intensity of the product category, the more likely is the emergence of a dominant design.

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

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 experience the event (the emergence of a dominant design) and one that will never experience it. The model simultaneously estimates coefficients for both the probability that the event will ever occur and the event's time, 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) use a split-population model of the determinants of banks' technology adoption, allowing some banks to be eventual nonadopters.[2]

For each of the N product categories i, we observe the duration t_i for products for which a dominant design occurred in the interval $[0, \tau]$ and the vector X_i of covariates. Let C_i be an indicator that denotes whether a dominant design occurred in $(0, \tau)$ for the ith product category; $C_i = 1$ if the observation is complete, and $C_i = 0$ if it is censored. The data are characterized by Type I censoring (right censoring) so that each product category has a fixed censoring time $\tau > 0$; t_i is observed if $t_i \leq \tau$; otherwise, $t_i > \tau$. Thus, $P(C_i = 1, t = t_i) = f(t_i)$ for the completed observations, and $P(C_i = 0) = P(t_i > \tau | X_i) = 1 - F(\tau) = S(\tau)$ for the censored observations. The log-likelihood function is

$$\text{(1)} \qquad LL = \sum_{i=1}^{N} \{C_i \ln[f(t_i)] + (1 - C_i)\ln[S(\tau)]\}.$$

Let $A = \{\ldots A_i, \ldots\}$ be an unobserved vector, where $A_i = 1$ if the ith product category witnesses the emergence of a dominant design and $A_i = 0$ if it will never witness a dominant design. We specify the probability of a dominant design's emergence as a function of the independent variables X_i: $\delta(X_i) = P(A_i = 1) = 1/[1 + \exp(\alpha X_i)]$, and $P(A_i = 0) = 1 - \delta(X_i)$. For product categories in which the dominant design emerges ($C_i = 1$), we also observe the time of its emergence, whereas when a dominant design does not emerge ($C_i = 0$), either a dominant design will never occur (i.e., $A_i = 0$) or a dominant design will eventually emerge, but beyond the observation period, in which case $t > \tau$. Thus, if a dominant design emerges during the observation period,

[2]For details on the statistics for the split-population model, see Schmidt and Witte (1989); for an application in a marketing context, see Sinha and Chandrashekaran (1992).

TABLE 2
Summary of Hypotheses and Results

Variable	Probability of Emergence of a Dominant Design	Time of Emergence of a Dominant Design
Appropriability	H_{1e}: The weaker the appropriability of the product category, the more probable is the emergence of a dominant design. (Supported)	H_{1t}: The weaker the appropriability of the product category, the shorter is the time to the emergence of a dominant design. (Supported)
Network effects	H_{2e}: The stronger the network effect in the product category, the less (more) probable is the emergence of a dominant design. (Less likely supported)	H_{2t}: The stronger the network effect in the product category, the longer (shorter) is the time to the emergence of a dominant design. (Not supported)
Value net	—	H_{3t}: The greater the number of firms in the value net of the product category, the shorter is the time to the emergence of a dominant design. (Supported)
Standards-setting process	—	H_{4t}: Compared with a de jure standards-setting process, a de facto standards-setting process in a product category results in a shorter time to the emergence of a dominant design. (Supported)
Radicalness of innovation	H_{5e}: The greater the radicalness of the product category, the less probable is the emergence of a dominant design. (Supported)	H_{5t}: The greater the radicalness of the product category, the longer is the time to the emergence of a dominant design. (Supported)
R&D intensity	H_{6e}: The greater the R&D intensity of the product category, the more probable is the emergence of a dominant design. (Supported)	—

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

and for censored observations,

$$(3)\qquad P(C_i = 0) = 1 - \delta(X_i) + \delta(X_i)[1 - F(\tau|X_i, A_i = 1)] = 1 - \delta(X_i) + \delta(X_i)S(\tau).$$

The log-likelihood function in Equation 1, when expressed as a function of the covariates X_i, is

$$(4)\qquad LL = \sum_{i=1}^{N}\{C_i(\ln[\delta(X_i)f(t_i|X_i, A_i = 1)] + (1 - C_i)\ln[1 - \delta(X_i) + \delta(X_i)S(\tau)]\}.$$

To estimate the effects of the covariates on the probability and the time of the emergence of a dominant design, we used the accelerated failure time specification, exploring alternative distribution functions $f(\cdot)$ for the base hazard. We implement the model within LIMDEP 8.0 (Greene 2002).

Data

We identified two product categories, office products and consumer durables, which have been extensively studied in prior research on market evolution (e.g., Agarwal and Bayus 2002; Golder and Tellis 1997). We used the historical method to collect data on the products (Golder 2000). We obtained information on the product categories from articles published in scholarly journals, books, and online business databases. We were able to collect complete information for 63 product categories (see Appendix A). All the data are from public sources.

Measures

Emergence and time of dominant designs. As we discussed previously, before the emergence of a dominant design, there are several technological changes in the product category. However, after a dominant design emerges, competition moves from competition between alternative product designs to competition within the dominant design. Guided by the distinctive characteristics surrounding the emergence of a dominant design, strategy researchers (Christensen, Suaréz, and Utterback 1998) have retrospectively identified a dominant design on the basis of when one design achieves market acceptance over other competing designs. We use this method to identify the emergence of dominant designs.

Three graduate students used archival sources (e.g., *Consumer Reports*, trade magazines, computing magazines) to develop histories of the evolution of product categories (for brief histories of two such categories, see Appendix B).

We then used two other graduate students to identify whether and when a dominant design emerged.

Following the convention for survival models (Lawless 2003), we used two variables to code the emergence of a dominant design. The first denotes whether a dominant design emerged in the product category. If a dominant design emerged, the variable was coded as 1, but if a single design specification was not favored by the market (e.g., video game consoles, camcorders), the variable was coded as 0. We observed dominant designs in 30 product categories. For the 33 product categories in which a dominant design had not yet emerged in 2003, the data were right censored. We define the second variable as the number of years between the introduction of the product category and the emergence of a dominant design. There were discrepancies between the two raters for 3 of the 30 product categories for the time measure, which we resolved using inputs from industry experts.

Given its centrality in our study, we used two checks of the measure of a dominant design. First, we used 11 industry experts to verify the year of the dominant design's emergence obtained from archival sources. The experts included five editors of trade journals (e.g., *Disk Drive Report*, *Computer Reseller News*, *Future Image Report*), two representatives of trade organizations (Consumer Electronics Association, DVD Forum), and four executives (e.g., Gartner Group, IDC). In most cases (26 of the 30 product categories in which a dominant design emerged), there was unanimous agreement between student raters and industry experts. In four product categories (fax machine, floppy drive, mainframe computer, and microprocessor chip), the dates for the dominant design's emergence differed by, at most, two years, which we reconciled by consulting with the industry experts.

Second, following the work of Anderson and Tushman (1990), we validated the measure of a dominant design with an objective measure of its market share performance. We obtained archival measures of market share for the dominant design for 24 of the 30 products in which a dominant design emerged. Using Anderson and Tushman's method, we coded the year in which the dominant design's market share exceeded 50% for four consecutive years. For these 24 products, the dominant design's time measure correlates highly (ρ = .86) with the time to the 50% market share threshold, reassuring us of the reliability of our measure.

Because there are no objective measures for appropriability, network effects, value net, and radicalness, we used raters to develop measures for these product characteristics. When feasible, we validated these measures with data from secondary sources.

Appropriability. Levin and colleagues (1987) conceptualize a product's appropriability as protection of R&D advantages for firms in the product category, covering the following six aspects: (1) patents (or copyrights) to prevent duplication, (2) patents (or copyrights) to secure royalties, (3) secrecy of product development effort, (4) lead time for product development, (5) speed in moving down the learning curve in product development, and (6) sales and service support. Because the sixth aspect is not related to innovation, we do not include it in our measure of appropriability.

We used two groups of expert raters to measure appropriability: academic experts (six professors from three business schools who are recognized experts on organizational innovation) and industry experts (two sets). Following the work of Levin and colleagues (1987), we asked the experts to rate (on a seven-point scale) the products on appropriability. We averaged the ratings separately for the two groups of raters. The higher a product category's rating on the scale, the weaker is its appropriability.

Network effects. Following the work of 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 used for the other measures): academic experts (four professors at two business schools who are recognized experts on organizational innovation) and MBA students (25 students with an average of three years' work experience). We asked the raters to rate direct and indirect network effects separately for each product category on a seven-point scale, ranging from 1 ("no effects") to 7 ("very strong effects"). We computed network effects for each product 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's (2000) radicalness measure, which has two dimensions: whether a new product incorporates a substantially different core technology (technology radicalness) and whether a new product provides substantially higher customer benefits relative to existing products (benefits radicalness). Both dimensions were assessed on nine-point scales. Six academics, all experts in organizational innovation, and ten graduate engineering students provided the radicalness ratings. We provided each rater with a brief history of each product category. We obtained the measure of radicalness for each product by adding each rater's ratings for technology and benefits radicalness and averaging 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, also gathered details on the value net of the product category (Amit and Zott 2001). 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 (90% of the cases). The counts for the remaining 6 products were resolved by a discussion between the raters and one of 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 as 0). There was unanimous agreement between the raters on the standards-setting process, which was reconfirmed with three academic experts.

R&D intensity. Consistent with prior research (Agarwal and Bayus 2002), we measured R&D intensity by the average R&D expenditure as a percentage of sales for each product category at the three-digit Standard Industrial Classification level.[3]

Recession at the time of product introduction. We measured recessionary environment using a categorical variable based on whether there was a recession in the U.S. economy in the year of first product introduction. We defined recession as two consecutive quarters of decline in gross domestic product.

Ratings from multiple raters. For the three explanatory variables of appropriability, network effects, and radicalness, multiple raters rated all the products. There are two ways that ratings from multiple raters may bias the estimates of the model. First, there is the potential for differences in the reliability of ratings across the raters (Van Bruggen, Lilien, and Kacker 2002). To account for this bias, we computed a weighted mean of the raters' ratings; the weight assigned to a rater was the reciprocal of the rater's absolute distance from the unweighted mean rating compared with other raters, as Van Bruggen, Lilien, and Kacker (2002) propose. Second, there may be a measurement error bias because the rating instrument may have induced each rater to provide a rating that differs from its "true" value.

We report results using the rater-bias adjusted ratings from academic experts, which accounts for differences in reliability of the ratings from multiple raters. As we report subsequently, we test for robustness of these estimates using ratings obtained from the other raters. In addition, we also implement a simulation procedure that examines the robustness of the parameter estimates to potential measurement errors.

[3]We obtained data for the R&D intensity from the Web (National Science Foundation, Division of Science Resources Studies 1999).

Results

Descriptive Statistics

In 33 (52%) of the 63 product categories, no dominant design emerged by 2003. The average time to the dominant design's emergence for the 30 product categories in which a dominant design emerged was 6.50 years. Table 3 contains the descriptive statistics and correlation matrix of the variables. Correlations are within acceptable limits (highest = .56, between network effects and the size of the value net), and the variance inflation factors were lower than ten (average = 1.48; maximum = 1.94), suggesting that multicollinearity is not a threat to the validity of the findings (Belsley, Kuh, and Welsch 1980).

Model Selection and Results

We estimated the model in Equation 5 using three distribution functions (lognormal, log-logistic, and Weibull) that accommodate a changing hazard rate. Although 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 = .23; σ = .31) suggest that the hazard function is mound shaped, increasing for the first six years and then decreasing. Although dominant designs emerged in only 30 of the 63 product categories (48%) during the period of observation, the hazard model suggests that, on average, there is a 60% chance that a dominant design would eventually emerge in the office products and consumer durables categories (see last row of Table 4).

We first discuss the effects of the control variables. The year of product introduction has no effect on the probability of emergence (b = 5.63, not significant [n.s.]) or on the time of emergence of a dominant design (b = 4.30, n.s.), whereas the presence of a recessionary environment (b = .70, p < .01) delays the emergence of a dominant design. In general, the results support the hypotheses. With respect to the prob-

TABLE 3
Descriptive Statistics and Correlation Matrix of Key Variables (n = 63)

Variable	Range of Variable	M (SD)	2	3	4	5	6	7
1. Time to the emergence of a dominant design (n = 30)	2–20	6.50 (4.96)	—[a]					
2. Appropriability	1–7	3.20 (1.94)	1.00					
3. Network effects	2–14	8.52 (3.12)	–.46**	1.00				
4. Number of firms in the value net	1–5	2.21 (1.10)	–.18	.56***	1.00			
5. Standards-setting process	0–1	54–de facto 85%	–.04	–.24*	–.17	1.00		
6. Radicalness	2–18	11.89 (2.11)	.11	–.04	–.09	–.11	1.00	
7. R&D intensity	1.67–9.00	7.40 (2.76)	–.03	–.17	–.05	.50***	.18	1.00

*p < .10.
**p < .05.
***p < .01.
[a]Correlations with the left-censored duration variable are not meaningful, and therefore we do not report them.

TABLE 4
Split-Population Model for Emergence of Dominant Design

Variable	Hypothesized Model	Single-Population Duration Model	Cutoff Year = 2002	Cutoff Year = 1998	Bootstrapping
Probability of Emergence					
Constant	–32.32 (733.18)		–31.20 (748.92)	–33.65 (788.46)	–31.31 (743.08)
Appropriability (H_{1e})	1.51 (.57)***	—	1.52 (.59)***	1.42 (.69)**	1.50 (.56)***
Network effects (H_{2e})	–.60 (.28)**	—	–.63 (.24)**	–.61 (.29)**	–.59 (.30)**
Radicalness (H_{5e})	–1.47 (.63)**	—	–1.47 (.62)**	–1.48 (.62)**	–1.47 (.63)**
R&D intensity (H_{6e})	.81 (.48)*	—	.82 (.50)*	.82 (.59)	.82 (.50)*
Year of product introduction	5.63 (96.15)	—	5.68 (97.30)	5.76 (99.30)	5.61 (97.84)
Time of Emergence					
Constant	–33.13 (151.75)	40.51 (287.00)	–30.20 (157.96)	–28.45 (162.02)	–32.59 (150.08)
Appropriability (H_{1t})	–.21 (.10)**	.29 (.14)**	–.21 (.09)**	–.22 (.10)**	–.21 (.09)**
Network effects (H_{2t})	.08 (.08)	–.14 (.11)	.08 (.08)	.08 (.08)	.08 (.08)
Number of firms in the value net (H_{3t})	–.35 (.12)***	–.20 (.20)	–.32 (.14)**	–.32 (.15)**	–.34 (.12)***
Standards-setting process (H_{4t})	–.88 (.24)***	–.03 (.56)	–.89 (.23)***	–.88 (.25)***	–.88 (.25)***
Radicalness (H_{5t})	.28 (.07)***	–.08 (.11)	.29 (.07)***	.28 (.08)***	.28 (.05)***
Year of product introduction	4.30 (19.89)	4.74 (37.78)	4.21 (20.317)	4.33 (22.65)	4.20 (19.46)
Recession during product introduction	.70 (.22)***	.12 (.43)	.69 (.21)***	.69 (.22)**	.70 (.21)***
σ of log-logistic distribution	.31	.74	.29	.29	.30
Log-likelihood	–44.15	–68.72	–41.82	–39.46	–44.04
Average predicted probability of emergence (δ)	.60	—	.60	.60	.61

*$p < .10$.
**$p < .05$.
***$p < .01$.
Notes: We show the parameter estimates and standard errors in parentheses.

ability of the emergence of a dominant design in a product category, as we hypothesized in H_{1e}, we find that appropriability has a positive effect (b = 1.51, $p < .01$), suggesting that the weaker the appropriability, the more likely is the emergence of a dominant design. As we hypothesized in H_{6e}, the greater the R&D intensity, the more likely is the emergence of a dominant design, though we obtain only marginal significance for this result (b = .81, $p < .10$). Conversely, as we hypothesized in H_{2e} and H_{5e}, respectively, network effects (b = –.60, $p < .05$) and radicalness (b = –1.47, $p < .05$) negatively affect the probability of emergence of a dominant design.

With respect to the time of emergence, as we hypothesized in H_{1t}, H_{3t}, and H_{4t}, respectively, weak appropriability (b = –.21, $p < .05$), the number of firms in the value net of the product (b = –.35, $p < .01$), and a de facto standards-setting process (b = –.88, $p < .01$) hasten the emergence of a dominant design. As we hypothesized in H_{5t}, radicalness (b = .28, $p < .01$) delays the emergence of a dominant design. We find no support for H_{2t} for the effect of network effects on the time of the emergence of a dominant design (b = .08, n.s.).

Next, we performed two model comparisons to examine the explanatory power of the split-population hazard model. First, we compared the proposed split-population hazard model with all explanatory variables for both the probability and the time of emergence with a baseline model that excluded the explanatory variables. A likelihood ratio test of the difference between the model with no explanatory variables and the proposed model ($\chi^2 = 51.92$, d.f. = 12, $p < .01$) indicated that the proposed split hazard log-logistic model outperformed this baseline model. Second, we compared the proposed model with a single-population model (i.e., incorporating only time; see Column 2 of Table 4). The proposed complete model outperformed the single-population model ($\chi^2 = 49.14$, d.f. = 5, $p < .01$). In addition, the parameter estimates change sign, and only appropriability has a significant, though 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

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 (though we do not report the results here). For both the probability and the time submodels, the coefficients are consistent in terms of their signs in the stepwise models with those we report in Table 4, reconfirming that multicollinearity is not a threat to the validity of our findings. Second, we tested for the effects of two additional control variables (both dummy coded): whether the candidate designs in the product category had a dominant firm sponsor, which we measured by sales revenue, at the time of product 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 time of the emergence of a dominant design, supporting the robustness of the model specification.

Censoring date. As we discussed previously, the censoring mechanism here is Type I, 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 the use of 2003 as the censoring date, we reestimated the model with alternative censoring dates: 2002, 2001, 2000, 1999, and 1998. We obtained consistent results, though, as may be expected, the significance levels of the parameter estimates varied 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.

Sampling variations. Although the sample size compares well with prior research, it is small; therefore, we performed a bootstrap analysis to examine the sensitivity of the results to sampling variations. The bootstrapping analysis (Column 5 of Table 4) indicated that the results were robust to sampling variations.

Use of multiple raters. To cross-validate the estimates obtained from the ratings of appropriability, network effects, and radicalness provided by the academic raters, we reestimated the model using the rater-bias adjusted ratings obtained from students and industry experts. These estimates were consistent with those we report in Table 4.

Effect of measurement errors. To assess the effects of measurement errors in ratings, we conducted a simulation (with 30 randomly generated samples) by assuming that the average ratings provided by the raters across different products are normally distributed in the population with mean and variance equal to the overall mean and variance (across all raters), respectively (i.e., $\overline{X} \sim N[\mu_{\overline{X}}, \sigma_{\overline{X}}]$), for each variable measured with error.[4] For the simulations, we set $\mu_{\overline{X}}$ equal to its observed mean in the sample, and $\sigma^2_{\overline{X}} = s^2_{\overline{X}}/(k - 1)$, where $s^2_{\overline{X}}$ is the observed variance in the sample and k is the number of raters. For each variable and for each rater, we drew a random number from $N(0, \sigma_{\overline{X}})$ and added that value to the rating of each product provided by that rater. We then computed the combined ratings across the raters as Van Bruggen, Lilien, and Kacker (2002) propose. We reestimated the split hazard model, once for each of the 30 random data sets generated, to obtain the mean and standard deviation of the estimates across the 30 simulations. The reestimated models provided results that were consistent with those we report in Table 4 (further details of the simulation procedure are available on request).

Direct and indirect network effects. We also separately examined the impact of direct and indirect network effects on the probability and time of emergence of a dominant design (though we do not report it here). The hypothesized

[4]We pursued this approach because there is currently no available theory for the assessment of measurement error biases in continuous-time accelerated failure time models with multiple constructs, multiple populations, and right censoring (Augustin 2005).

model (Bayesian information criterion value = 143.49) outperformed the disaggregated network effects model (Bayesian information criterion value = 151.83). In the disaggregated model, direct network effects have a weak effect ($p < .01$) on the probability and time of emergence of a dominant design, whereas indirect network effects have no effect on either. We conjecture that our inability to account separately for the direct and indirect network effects on the emergence of dominant design may be because both direct and indirect network effects coexist ($\rho = .25$, $p < .01$) and jointly determine the dynamics of dominant design emergence.

Predictive Validity

Emergence of dominant design. Because the data are right censored at 2003, we may not observe the emergence of a dominant design in a product category during the observation period, because (1) a dominant design may never emerge in that category or (2) a dominant design may emerge after 2003. We selected a subset of product categories introduced in or before 1984 (n = 42) and used the model to predict the probability of emergence of the dominant design. The cutoff date of 1984 provides 20 years of observations after product introduction, or three standard deviations beyond the average time for dominant design emergence that we observed in our data. Thus, we can be reasonably certain that a dominant design is unlikely to emerge in those product categories after 2003.

The split-population log-logistic hazard model predicts (1) the emergence of a dominant design for 14 categories, 12 of which had witnessed the emergence of a dominant design by 2003, and (2) no emergence of a dominant design for 28 categories, 18 of which had not witnessed the emergence of a dominant design, resulting in a false-positive rate of 14% and a false-negative rate of 36%. By means of the criterion that Morrison (1969) advocates for evaluating the predictive performance of discriminant analysis models, the overall proportion of correct classification is .71, which compares favorably with the proportional chance C_{pro} of .50; $C_{pro} = [\alpha]^2 + [1 - \alpha]^2$, 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 ($\chi^2 = 12.92$, d.f. = 1, $p < .01$). We obtained similar results in the predictions of the emergence of a dominant design when we used alternative cutoff years of 1981 ($\chi^2 = 13.17$, d.f. = 1, $p < .01$) and 1987 ($\chi^2 = 10.32$, d.f. = 1, $p < .01$).

Time of emergence of a dominant design. To evaluate the model's ability to predict the time of emergence of a dominant design, we applied jackknifing, using data for the 30 products for which there was a dominant design. We held out one target product, reestimated the model on the other 29 products, and then used the estimated parameters to predict the emergence of a dominant design for the remaining products. We computed the mean absolute deviation (MAD), defined as $(l/n)\Sigma_{i=1}^{n}|D_{ia} - D_{ip}|$, where D_{ia}, D_{ip}, and n denote the actual time to the emergence of a dominant design for product i, the predicted time of the emergence of a dominant design for product i, and the number of products (n = 30), respectively.

The MAD using the predicted model is 2.49 years compared with a MAD without the model of 3.43 years, an improvement of 27%. A post hoc examination of absolute deviations indicates that elimination of two products (color television and audiocassette player) reduces the MAD for the predicted model to 2.20 years compared with a MAD without the model of 3.40 years, an improvement of 35%. Our small sample size precludes the determination of why these two products have such high leverage on model performance. Overall, the two predictive validity tests demonstrate that the split-population hazard model predicts both the probability and the time of the emergence of a dominant design well.

Discussion

We investigated the emergence and the time of emergence of a dominant design in a product category as a function of its product-market characteristics, allowing 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 time of the emergence of a dominant design, conditional on its emergence.

Theoretical Contributions

Our findings contribute to the literature in marketing that explores product and market evolution. The findings suggest that a split-population model that allows for the nonemergence of a dominant design in some product categories offers a better way to model the factors that influence the emergence of dominant designs than a single-population hazard model. The split-population model can be extended to other product and market evolution processes, such as product takeoff, to account for the possibility that some products may never take off (e.g., Sony minidisk, quadraphonic sound).

We find 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 time of emergence of a dominant design. The facilitating role of weak appropriability on both the probability and the time of emergence of a dominant design suggests that appropriability has opposing effects on firms' quests for securing rents from innovations (Teece 1986). On the one hand, weak appropriability results in a 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 a dominant design, increasing rents for all firms in the market. The negative effect of network effects on the probability of the 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 the 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 adverse effects of coordination costs of interorganizational relationships. For the product categories in this study, the added rents from the value net appear to outweigh the added transaction costs, thus hastening the emergence of a dominant design.

Likewise, the results indicate that a dominant design is likely to emerge sooner in product categories in which the standards-setting process is de facto (versus de jure). This is consistent with prior theoretical work in economics (e.g., Farrell and Saloner 1988) 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, the results for R&D intensity suggest that dominant designs are more likely to occur in R&D-intensive categories; the higher investments in the product categories perhaps provide the necessary variation in designs, which in turn create pressures for the selection of a dominant design.

Managerial Contributions

The study's findings have some clear implications for managers. First, the results suggest that managers should realize 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 probability and the time of emergence of a dominant design. In addition, market-based de facto standards-setting processes (versus de jure standards-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 might consider strategies to weaken appropriability and also encourage de facto standards-setting processes. For example, IBM and Intel's decision to share know-how for blade servers may be an attempt to hasten the emergence of a dominant design using a de facto standards-setting process (*The Wall Street Journal* 2004).

Second, the model can be used to predict the probability and time of emergence of dominant designs. These predictions can be useful to managers in the *ex ante* planning of marketing strategies. For example, of the products in our data set that have not yet had dominant designs emerge, the product category with the highest probability is satellite radio ($p = .86$), and the product category with the least likely probability is instant messenger ($p = .01$). It will be interesting to observe whether these predictions turn out to be accurate.

Limitations and Further Research

This study has some limitations that present opportunities for further research. We primarily focused on the time to the 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 that result in several dominant designs. Indeed, in some product categories (e.g., operating systems for PCs, spreadsheet software), the initial dominant design was replaced by a subsequent design. To extend the findings from this study, further research could address the emergence of multiple, sequential dominant designs, perhaps through a repeated-events, split-population hazard modeling approach.

Given our focus on the development of a cross-product category model in which objective measures of some variables were not available, we used retrospective measures for some constructs, obtaining them from knowledgeable raters. With improved record keeping, future researchers could use measures that are not subject to the possible hindsight biases and measurement errors associated with these measures. Alternatively, researchers could consider focusing on a specific product category (e.g., Shankar and Bayus 2003), which may enable the use of objective measures within the product category.

The emergence of a dominant design may also be influenced by the strategic characteristics and actions of firms, including their collateral assets (Teece 1986), product portfolios, and strategic maneuvering (Cusumano, Mylonadis, and Rosenbloom 1992). Further research could extend our study by incorporating such firm-level factors.

We hope that we have contributed in some distinct way to the theory base that helps explain the emergence of dominant designs. We also hope that our approach and modeling framework are helpful for managers who need to devise strategies that reduce the uncertainty about the dynamics of evolution of markets for technology products.

APPENDIX A
Product Categories (n = 63)

Product Category	Year of Product Introduction	Time to the Emergence of a Dominant Design	Specifications of a Dominant Design
1. 3.5″ floppy drive	1979	1984	Sony's design
2. AM stereo	1982	1986	Motorola's C-Quam System
3. Answering machine	1962	—	—
4. Antivirus software	1982	—	—
5. Audiocassette player	1962	1969	Philips's design
6. Automatic teller machine	1967	—	—
7. Cable modem	1995	1998	DOCSIS specifications
8. CAD software	1982	—	—
9. Camcorder	1984	—	—
10. Camera phone	2000	—	—
11. CD player	1982	1985	Philips–Sony's design
12. CD-ROM drive	1983	1986	Sony's design
13. Cellular phone	1979	—	—
14. Color television	1951	1957	National Television System Committee
15. Cordless telephone	1975	—	—
16. Database software	1981	1986	Server Query Language (SQL)
17. Desktop publishing software	1984	1987	Adobe Pagemaker
18. Dial-up modem 56 K	1979	1998	56KFlex
19. Digital camera	1991	—	—
20. Dot matrix printer	1964	1968	ESC/P from Epson
21. DSL modem	1996	1999	G.Lite
22. DVD player	1996	1999	DVD design from Zenith
23. Electric toothbrush	1960	—	—
24. Fax machine	1960	1983	GIII
25. File-zipping software	1986	—	—
26. Flash memory	1988	—	—
27. Flatbed scanners	1978	—	
28. Food processor	1972	—	—
29. Graphics software	1990	1996	Adobe Photoshop
30. HDTV	1987	1993	Standard Definition Television
31. Home microwave oven	1955	—	—
32. Inkjet printer	1984	—	—
33. Instant messenger	1998	—	—
34. Instant photography	1948	1955	Polaroid
35. Internet service providers	1980	—	—
36. Internet telephony	1997	—	—
37. Laser printer	1984	—	—
38. Mainframe computer	1946	1964	IBM 360
39. Microprocessor chip	1971	1979	Intel 4004
40. Mini audio disc	1992	—	—
41. Notebook computer	1980	—	—
42. OCR software	1974	—	—
43. Operating system for PCs	1977	1984	MS DOS
44. Pager	1974	—	—
45. PC	1975	1983	IBM PC
46. Personal digital assistant	1993	—	—
47. Personal finance software	1983	1987	Intuit
48. Photocopiers	1950	1959	Xerox 914
49. Pocket calculator	1971	—	—
50. Portable file document software	1993	1999	Adobe PDF
51. Presentation graphic software	1986	1991	Harvard Presentation Graphics
52. Projection television	1973	—	—
53. Satellite radio	1998	—	—
54. Single-use camera	1986	—	—
55. Spreadsheet software	1979	1984	Lotus 1-2-3
56. Super audio CDs	1999	—	—
57. Video game console	1971	—	—
58. Home video recorders	1975	1978	JVC VHS
59. Web camera	1991	—	—
60. Web server software	1995	—	—

APPENDIX A
Continued

Product Category	Year of Product Introduction	Time to the Emergence of a Dominant Design	Specifications of a Dominant Design
61. Word-processing software	1979	1983	Wordstar
62. Work station	1980	1986	Sun's Unix
63. Zip drives	1995	1997	Iomega

Appendix B
Brief Histories of Two Product Categories

Camcorders (Dominant Design Did Not Emerge)

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

In January 1985, several Japanese firms, including Canon, Fuji, Pioneer Electronic, Kyocera, Aiwa, Sanyo, and Ricoh, licensed Sony's 8 mm camcorder technology. In February 1985, 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 received 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 8 mm and the VHS-C formats enjoyed fluctuating popularity in the market, and neither format gained 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 this 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.

DVD Players (Dominant Design Emerged)

In an attempt 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. The objective of the DVD consortium was to establish the DVD standard as an open format. In addition, the DVDs were encoded with the Dolby Digital sound process to be compatible with virtually all home theater electronics.

However, the DVD format for DVD 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 could play all DVDs, but DVD players could not play DIVX discs, which were 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, and studio support for DIVX never materialized. By May 1999, approximately two million DVD players had been shipped to retailers, compared with approximately 165,000 DIVX players. At the same time, there were 3317 DVD movie titles available on the DVD format, whereas only 471 titles were available on the DIVX format. In June 1999, Circuit City withdrew DIVX from the market, and the DVD format emerged as the dominant design.

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