THE CONDITIONING EFFECT OF TIME ON FIRM SURVIVAL:
AN INDUSTRY LIFE CYCLE APPROACH

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In an effort to reconcile theoretical “blind spots,” we integrated research in technology management, organizational ecology, and evolutionary economics. The central premise underlying the resultant model is that time conditions the effects of age, contemporaneous size, order of entry, and contemporaneous density on mortality rates. We tested our hypotheses using a life cycle approach and data on 33 product innovations that span most of the 20th century. Results resoundingly support our central thesis on the impact of time on both survival rates and relationships previously thought to be universalistic.

Driven by environmental forces and innovation, industries evolve through prototypical phases of a life cycle and undergo irreversible transformations in their competitive dynamics, organizational diversity, and structures. According to a selection perspective, the evolutionary process changes the source of competitive advantage in an industry, especially the knowledge and scale resources associated with barriers to entry and survival (Anderson & Tushman, 1990; Gort & Klepper, 1982; Nelson & Winter, 1982). For example, technology studies have argued that the onset of an industry’s “dominant design” implies intensification of scale barriers and greater emphasis on incremental process innovation over radical product innovation capabilities (Utterback & Abernathy, 1975).

Evolution thus introduces a dynamic element into selection processes, since firms face very different competitive environments before and after transformations. In fact, there are indications that life cycle phase may have both founding and contemporaneous effects on survival. Although cohorts of firms that enter before and after such structural transformations face very different founding conditions, their risks of survival are also likely to vary according to current competitive contexts. Failing to distinguish between cohorts of organizations that differ owing to evolution-related discontinuities implies a false equivalency across organizations (Baum, Korn, & Kotha, 1995). This observation, then, suggests the need for a time-variant approach to investigating relationships between various organizational and environmental characteristics and firm survival. By adopting this conditioning view of time, our research addresses the ahistoricism that ironically typifies evolutionary studies of organization populations.

Our investigation addresses potentially important issues. First, relying on life cycle research, we identified temporal discontinuities based on the intensification of barriers to entry. Studies on dominant design have made significant contributions to explaining how technology evolution affects firm survival (Suarez & Utterback, 1995), but not all industries experience a dominant design (Klepper, 1996). However, the evolutionary trajectories of diverse long-lived organizations appear to follow a common path from birth to maturity (Gort & Klepper, 1982; Hannan & Carroll, 1992), indicating the possibility of alternate lead-ins to entry barriers. We integrated three parallel research streams—organizational ecology, evolutionary economics, and technology management—and identified several factors that contribute to structural transformation. Thus, while consistent with existing literature, our conceptualiza-

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tion of life cycle phases allows for a more general empirical discernment of this transition.

Second, studies of organizational populations have been criticized for their lack of attention to time-variant effects (Baum, 1996). Temporal changes in the basis of competitive advantage imply that the type of firm at risk of failure may be closely linked to the life cycle stage of the industry (Klepper & Graddy, 1990; Suarez & Utterback, 1995). This notion highlights the need to explore how life cycle effects may influence failure patterns as they interact with various causal factors. More specifically, this study is the first to our knowledge that examines how life cycle phases interact with variables related to a firm's demographic characteristics (size and age), ecology (industry density), and strategy (timing of entry) to accentuate or mitigate their impacts on firm survival.

We provide empirical evidence for our hypotheses by investigating histories of several innovations introduced at different points during the 20th century. Using longitudinal data on 3,431 firms that represent the universe of all firms entering 33 industries between 1908 and 1991, we bring in the crucial element of generalizability that is lacking in single-industry studies.

LITERATURE REVIEW

Empirical research has shown that the evolutionary trajectories of diverse organizational populations across industries appear to follow a prototypical path from birth to maturity. The number of organizations grows slowly at first and then increases rapidly until the population reaches a peak. Thereafter, the process reverses and, despite continued growth in industry output, the population declines and a few large firms come to dominate the market. This evolutionary pattern has been observed with remarkable consistency across studies in organizational ecology, evolutionary economics, and technology management. We begin by discussing each of the three perspectives and then build an integrative time-variant model.

Evolutionary Economic Models

In explaining market structures at equilibrium, evolutionary economists (Gort & Klepper, 1982) have developed models that include past episodes of technological innovation that have spurred industrial evolution and thus address the problem of ahistoricism that is typically associated with traditional structural and game-theoretic economic models (Malerba & Orsenigo, 1996). Based on Schumpeterian thinking (e.g., Schumpeter, 1934, 1950), the fundamental issues in evolutionary economics relate to competition as a process of endogenous change and to the dynamic two-way relationship between the variety (the range introduced) and selection (the relative economic importance of competing alternatives) of innovations (Hodgson, 1993; Witt, 1992). Although opportunities, available resources, and incentives to innovate determine variety, dynamic selection mechanisms operate through innovative entries of new firms, exits of unprofitable firms, and changes in the relative importance of surviving technologies (Metcalfe, 1994).

Researchers in this tradition have argued that the relative innovative advantages of entrant and incumbent firms depend upon the source of knowledge leading to innovative activity. Accordingly, knowledge conditions determine patterns of entry, growth, and exit and thus, evolutionary processes (Audretsch, 1997; Gort & Klepper, 1982; Klepper & Graddy, 1990; Nelson & Winter, 1982). More specifically, Nelson and Winter (1982) distinguished two types of innovation periods—"Schumpeter mark I" (widening innovations that decrease concentration ratios) and "Schumpeter mark II" (deepening innovations that increase concentration ratios)—and argued that an industry’s technological regime, which determines properties of the knowledge base that underpin firms’ innovative actions, changes over time and thus influences variety and selection processes (Breschi, Malerba, & Orsenigo, 2000). The first period, termed the entrepreneurial regime (Winter, 1984), is characterized by Schumpeter’s “creative destruction” and a widening pattern of innovative activities as new entrants enlarge the innovative base of an industry. During this period, sources of knowledge critical to generating radical innovations lie outside established routines (Winter, 1984). Firms pursue multiple technology trajectories because uncertainty surrounds users’ preferences and the technological means of satisfying them (Dosi, 1982). Thus, entering firms act as agents of change and play a key role in industrial dynamics (Gort & Klepper, 1982).

The latter period, termed the routinized regime (Winter, 1984), represents creative accumulation and a deepening pattern of innovation as system-wide compatibility and integration become vital (Farrell & Saloner, 1985; Hughes, 1983). Innovative activity is determined by the accumulated stock of nontransferable internalized market-based expertise (Gort & Klepper, 1982; Nelson & Winter, 1982). Accordingly, established firms are favored as existing hierarchies, learning, and “path-dependent” collateral assets—such as reputation, market information, distribution networks, and patent hold-
ings—become key to competitive advantage and pose significant barriers to entrepreneurial entry (Malerba & Orsenigo, 1996).

Low start-up costs in the early years of an industry facilitate easy entry, particularly by firms armed with product innovations. However, a change in the technological regime increases minimum efficient scale barriers and sunk costs. As incumbents focus their R&D efforts on process innovations, price is driven down. Incumbent advantage grows, and increasing levels of product innovation expertise is required for profitable entry (Klepper, 1996). Because of the transition, therefore, rising entry barriers make it difficult for new firms to enter the market, and existing firms undergo severe survival tests. Reduction in entries, combined with exits of less successful firms, results in decreased variation in product design and leads to the emergence of a dominant design (Klepper, 1996). As a shakeout ensues, only firms that are able to attain sufficiently low costs and high quality survive (Jovanovic & MacDonald, 1994; Klepper & Graddy, 1990). The level of concentration in the industry increases as a few large players come to enjoy disproportionate market power. Over time, opportunities arise for small firms to profitably enter because incumbents have low incentive to innovate and are willing to tolerate small firm entry (Klepper, 1996). The evolutionary economics model thus links systematic changes in the character, importance, and sources of innovations to various evolutionary stages of an industry.

Technology Management Studies

A parallel and closely related body of research suggests that technological cycles shape the form and level of competition, the attractiveness of entry, and industry structures. Accordingly, it is argued that the historical-structural relationships among organizations that are shaped by ecological and industrial dynamics actually reflect underlying technological changes (Baum, Korn, & Kotha, 1995).

Technological change is conceptualized as a sociocultural evolutionary process of variation, selection, and retention (Anderson & Tushman, 1990; Campbell, 1969). Variation is driven by technological discontinuities as the core technology of an industry evolves through long periods of incremental change punctuated by times when radical, new, superior technologies displace old, inferior ones (Tushman & Anderson, 1986). The ensuing era of ferment (Tushman & Anderson, 1986) is characterized by competition for dominance among multiple variants of the new technology and existing technologies. Selection mechanisms and, therefore, the locus of entrants’ and incumbents’ relative advantage, depend on whether a new technology builds on existing skills (is competence-enhancing) or renders them obsolete (is competence-destroying) (Cooper & Schendel, 1976; Henderson & Clark, 1990; Tushman & Anderson, 1986). A supplemental argument suggests that a competency-destroying new technology may destroy the value of specialized complementary assets owned by incumbents that typically give them advantages over entrants (Teece, 1986; Tripsas, 1997).

Thus, technological ferment creates market opportunities for entrepreneurs and increases their propensity to establish new firms as a means to generate and appropriate entrepreneurial profit (Shane, 2001). Entry is encouraged when technology creates new customer niches in which performance on established metrics can be lower but performance on new product attributes must be high (Christensen & Bower, 1996). Over time, the uncertainty abates as the period of substantial product-class variation ends with the emergence of a dominant design—a single architecture that establishes dominance in a product class (Abernathy, 1978; Abernathy & Utterback, 1978; Utterback & Abernathy, 1975). A wave of failures occurs among firms that have not mastered the dominant technology. In this era of incremental change (Tushman & Anderson, 1986), new entry is discouraged by heightened barriers to entry, which are related to collateral assets such as reputation, market knowledge, and distribution and supplier networks, as well as to experience effects and scale economies due to standardization (Abernathy, 1978; Anderson & Tushman, 1990; Utterback & Suarez, 1993). Technological advancement thereafter becomes incremental and process-oriented, focusing on improving the performance trajectory of the dominant technology. Over time, inertia may erode some incumbent advantages, thus creating opportunities for a mild resurgence of new entry. Accordingly, technology cycles are argued to have profound influences on patterns of organizational founding and failure.

Organizational Ecology

Simultaneously, ecologists have linked the evolution of organizational populations to dynamic models of competition to explain organizational diversity. Density-dependence theory explains the dynamics of organizational populations on the basis of the number of organizations in a population (Hannan, 1986; Hannan & Carroll, 1992; Hannan & Freeman, 1989). Initially, increasing density cre-
ates mutualism by enhancing the institutional legitimacy of a population and the ability of its members to attract resources. Legitimacy thus boosts founding rates while reducing failure rates. However, as the population continues to grow, the relative scarcity of resources creates a competitive interdependence between members. In fact, the intensity of competition increases at an increasing rate as population density increases, with an adverse effect on founding and survival. Combined, these two opposing forces, legitimacy and competition, suggest an inverted U-shaped relationship between density and organizational founding, and a U-shaped relationship between density and failure.

Density dependence provides an explanation for the shape of the growth trajectory of a population of organizations until its peak size, but not for the subsequent decline in number of firms and market concentration. In order to address this lacuna, Carroll and Hannan (1989) proposed that an organization’s risk of failure is affected not only by the density of the population of which it is a member at any given time, but also by the density of the population at its time of founding. High density at founding creates a liability of resource scarcity, which prevents newly founded organizations from full-scale operation, and tight niche-packing, which forces them to use resources that are inferior to those of established organizations. Organizations founded in high-density periods therefore experience persistently higher failure rates, which explains the observed decline in a population’s density from its peak.

Implicit in the density model and its predictions is the notion that competitive processes change substantively over the course of an organization population’s history (Baum, 1995). As populations undergo a change from “r-selection” to “K-selection,” the basis of competitive advantage shifts from order of entry to efficiency (Brittain & Freeman, 1980). The initial period of slow but exponentially increasing rate of founding gives way to slower growth rates as an environment’s carrying capacity is tested. Simultaneously, the advantage shifts from new firms that are capable of moving quickly to occupy new resource positions, to larger, generalist organizations that cater to broad customer bases and can withstand high levels of uncertainty. During the ensuing shakeout, the competitive advantages of size enable larger firms to marginalize their smaller rivals. This process reduces density and raises level of concentration. However, as the level of concentration rises, the mortality of generalist firms increases as they compete with each other to gain control of the center of the resource space (Carroll, 1985). In such a concentrated market, small specialist firms get access to resources and pockets of demand located on the periphery of the resource space that they can exploit without entering into direct competition with the larger generalists. The resulting resource partitioning creates organizational subgroups that fill complementary roles in the market and thus allows a mild resurgence in density after the shakeout.

Although past ecological research has typically treated the effects of competition as time-invariant, recent research by Baum (1995) is a precursor to our work on the conditioning effects of ecological processes on time. Noting the earlier-mentioned limitation of density-dependence theory, Baum (1995) incorporated size-based competitive asymmetries into density-dependence models and, more importantly from our perspective, allowed the effects of competitive processes to vary over a population’s history. His findings indicated the importance of incorporating time variation in competitive processes into evolutionary studies.

THEORETICAL FRAMEWORK

The key arguments offered within each of the models discussed above—economics, technology management, and organizational ecology—are summarized in Table 1. As is evident, each model emphasizes evolutionary processes of variation, selection, and retention. However, the implicit assumptions of the different models make each model more applicable to certain industry populations than to others.

Integrating ecological and institutional perspectives, density models relate the prevalence of other organizations to a population’s vital rates of founding and failure. Although the strength of density-based evolutionary models lies in their generalizability and applicability over a range of organizational populations, they have so far failed to adequately account for the decline in density and the concentration in size distribution that are often observed (see Barron, 1999). In this regard, the complementarity of economic and technology models lie in their explicit focus on market concentration and the decline in numbers following a structural discontinuity.

Technology management and evolutionary economics studies relate evolutionary trajectories to technological underpinnings, and they define the two periods of an industry’s evolution similarly; evolutionary studies refer to entrepreneurial and routinized regimes, and technology studies, to eras of ferment and of incremental change. The key difference between the two frameworks is that tech-
TABLE 1
Summary of Theoretical Perspectives on Industry Evolution

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Growth Phase</th>
<th>Mature Phase</th>
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<tr>
<td><strong>Evolutionary economics</strong></td>
<td><strong>Entrepreneurial regime</strong></td>
<td><strong>Routinized regime</strong></td>
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<td>Gort &amp; Klepper (1982); Nelson &amp; Winter (1982); Winter (1984); Jovanovic &amp; MacDonald (1994); Klepper (1996)</td>
<td>The source of information and knowledge critical to generating innovations during this stage lies outside established routines and industry sources. Knowledge advantage lies with entrants since product innovation (where entrants have advantage) is more important than process innovation (where incumbents have advantage). Entrants come into the market to exploit the value of their information.</td>
<td>Focus shifts to process innovations and cost-based competition. Innovation is determined by accumulated stock of internalized market-based expertise that only incumbents can possess. Increase in entry/survival barriers (mainly scale-related) cause decline in entry rates and shake out weaker firms from the market. A few large firms gain market power as the industry concentrates. Some opportunities for profitable entry may persist over time owing to strategic disincentives for incumbents engaging in product innovations or to innovative inefficiencies resulting from largeness.</td>
</tr>
<tr>
<td><strong>Technology studies</strong></td>
<td><strong>Pre-dominant-design era/Era of ferment</strong></td>
<td><strong>Post-dominant-design era/Era of incremental change</strong></td>
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<tr>
<td>Utterback &amp; Abernathy (1978); Anderson &amp; Tushman (1992); Tushman &amp; Anderson, (1986); Baum, Korn &amp; Kotha (1995); Suarez &amp; Utterback (1995)</td>
<td>Technological discontinuities produce a succession of innovations in a product class, creating new markets and dramatic improvements in performance. This period is characterized by substantial product class variation as new firms enter with their versions of technological innovation. Rivalry between alternate technological standards creates profound uncertainty.</td>
<td>The setting of the dominant design creates entry barriers and triggers a shakeout of firms that are unable to integrate all aspects of this technology successfully, leading to a sharp decline of firms and subsequent stabilization. Subsequently, technological progress occurs incrementally through modifications to the dominant design. Over time, incumbent inertia creates openings for specialized entry.</td>
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<td><strong>Organization ecology</strong></td>
<td><strong>Period of growth</strong></td>
<td><strong>Period of decline and resurgence</strong></td>
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<td>Baum (1995); Hannan (1986); Hannan &amp; Carroll (1992); Hannan &amp; Freeman (1989); Carroll &amp; Hannan (1989); Brittain &amp; Freeman (1980); Carroll (1985)</td>
<td>Initially, increasing density increases legitimacy at a decreasing rate, during which period founding rates increase and failure rates decrease. Over time, selection pressures become stronger as the population approaches its carrying capacity. Increasing density now increases competition at an increasing rate, with detrimental effects on founding and failure rates.</td>
<td>The liability of scarceness and tight niche packing lead to genetic weaknesses in organizations founded during high-density periods, which in turn lead to a decline in the number of organizations relative to the peak. Selection processes favor large, generalist organizations. Over time, a bimodal size distribution occurs as increasing market concentration pushes large incumbents toward the center of the resource space, freeing up the periphery for smaller, specialized entrants.</td>
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nology scholars attribute the shift between the two eras to the setting of a dominant design, whereas evolutionary economists question the exogenous nature of dominant designs. Citing Porter's (1983) work to show that not all industries adopt a dominant design, Klepper (1996) additionally contended that convergence on a single dominant design may be actually the outcome of competitive processes that lead to reduction in the diversity of product innovation, rather than the cause. At any rate, both these approaches appear to be more appropriate to technologically intensive environments that are rich with opportunities for product and process innovation. However, similar patterns in populations of service and nonprofit organizations (Hannan & Freeman, 1987, 1988) prompted Barron (1999) to comment on the limited generalizability of technology- and innovation-based evolutionary approaches to environments that are not characterized by technological intensity. In the face of this limitation, incorporating insights across models appears to have utility.

Thus, the key mechanisms of knowledge regime in evolutionary economics, dominant design in technology management, and density in ecology appear to be complementary explanations of evolutionary dynamics. Each approach has its own strength and weaknesses, with relative advantages in particular contexts. An integrative approach enables us to examine a diverse set of populations in which evolutionary dynamics do not depend on idiosyncratic industrial characteristics or particular historical events, or for which data are simply not available.

### Life Cycle Phases

A common theme throughout these theoretical expositions is the discontinuous transformation of competitive conditions at a particular point in an industry's evolution. This watershed is an integral aspect of evolutionary literature. As illustrated in Table 1, ecologists distinguish between periods of pre- and post-peak density (Baum & Powell, 1995); technology studies discriminate between pre- and post-dominant-design phases (Baum et al., 1995; Suarez & Utterback, 1995; Utterback & Abernathy, 1975); and evolutionary economists differentiate between entrepreneurial and routinized regimes (Audretsch, 1997; Nelson & Winter, 1982). Regardless, however, of whether the underlying rationale relates to the emergence of a dominant design, an evolving technological regime, or competitive intensity, there appears to be convergence on the notion that at a particular point in time in an industry's history, a structural change occurs that changes the resource conditions associated with competitive advantage. Barriers to entry and survival undergo a discontinuous transformation that has profound influences on organizational founding and failure rates and on the character of competition in an industry. We elaborate below on this common theoretical underpinning, the transformation of barriers to entry and survival, that discriminates between a pretransformation growth phase and a posttransformation mature phase.

The concept of entry deterrence is founded on the general premise that an array of structural characteristics in an industry pose conditions adverse to market entry (Bain, 1956). These entry barriers aid market incumbents in limiting the number of new competitors and the intensity of new competition. A transformation in structural barriers is consistent with the ecological emphasis on increasing competitive pressures that place various kinds of resource constraints on new entrants (Hannan & Freeman, 1977) as an industry evolves. Drawing from the other two literature streams, we expand on this theme and argue that resource constraints can stem from knowledge, efficiency (scale) and network sources. Knowledge barriers stem from a shift to a routinized technology regime or era of incremental change, a shift that benefits incumbents by emphasizing process innovations and "learning curves" over entrepreneurial product innovations (Abernathy & Utterback, 1978; Gort & Klepper, 1982; Nelson & Winter, 1982; Tushman & Anderson, 1986). The accompanying efficiency barriers result from the increasing relevance of economies of scale in R&D, production, and learning (Klepper, 1996) and from increasing reliance on standardization and the ability to design interchangeable parts (Abernathy, 1978; Anderson & Tushman, 1990; Suarez & Utterback, 1995), which favor large-scale production. Further, network structures get reinforced with the transition to the mature period, making it difficult for late entrants to form interfirm relationships and institutional ties (Madhavan, Koka, & Prescott, 1998). The resultant resource barriers benefit incumbents and make it difficult for entrants to break into established networks.

In sum, a confluence of forces increases entry barriers to such levels that at one point of time, new entry drastically diminishes, possibly even ceases. Following the structural change, exit continues as less fit firms are forced out of the market. However,
Consistent findings in both ecology and evolutionary economics research have indicated that the mortality rate in a population of firms tends to decline with age. Population ecologists have noted the vulnerability of young organizations to selection processes that favor structural inertness, and consequent accountability and reliability. Young, resource-strapped organizations have to internalize and learn new roles as social actors (Hannan & Freeman, 1989). They lack links with external stakeholders (Freeman et al., 1983) and thus find it difficult to attract customers away from established, older organizations. Economists attribute the liability of newness to the costs of information acquisition and to path-dependent (historically determined) organizational learning processes (Geroski, 1995; Jovanovic, 1982). Since the accumulation of competitive resources and capabilities happens over time, age is positively related to survival.

The various shortcomings associated with youth are likely to be more disadvantageous during the mature phase than during the growth phase. During an industry’s growth years, there is a greater fit between entrants’ knowledge capabilities and the knowledge conditions generating innovative activity. The advantage lies with new firms, since the sources of information critical to generating the innovative activity during this phase lie outside routines practiced by incumbent firms (Williamson, 1975). Thus, as Gort and Klepper (1982) argued, entrants play an important role during the growth years. In their disequilibrating role, entrants help markets (Christensen, Suarez, & Utterback, 1998) to evolve and restructure their population characteristics over time. As Winter noted, “An entrepreneurial regime is one that is favorable to innovative entry and unfavorable to innovative activity by established firms; a routinized regime is one in which the conditions are the other way around” (1984: 297).

An additional rationale relates to criteria for the evaluation of firm reliability and accountability—issues highlighted in the ecology literature. In the growth period, undefined roles and malleable institutional environments characterize a market, and uncertainties regarding the “correct” technology and sustainable business model lead to a period of experimentation along multiple trajectories. In this tentative environment, the survival disadvantage associated with a new firm’s lack of reliability and accountability is reduced by the absence of a uniform yardstick for performance or institutionally mandated behavior. Absence of established reference points and a period of experimentation encourage tolerance and a higher threshold of censure.

Temporal Hypotheses

To achieve the related goals of explaining organizational diversity and industrial structure, however, it is crucial to understand the impact of the temporal discontinuity associated with industry transformation for distributions of organizational size, age, entry timing, and density. Our discussion till now suggests that this temporal discontinuity is likely to condition patterns of competition, and thus the basis of variation and selection, by redefining sources of competitive advantage. The dynamics of organizational populations and industries are critically influenced by the context of the change in competitive landscape within which they occur (Baum, et al., 1995). Given this influence, we adopted a time-variant approach in this study. By addressing time-variant implications of demographic processes (age and size), ecological processes (density), and strategic processes (timing of entry) for firm survival, we can observe that the effects of these variables change systematically as markets evolve through their life cycles.

Organizational age: The liability of newness.

Consistent findings in both ecology (Carroll & Delacroix, 1982; Freeman, Carroll, & Hannan, 1983) and evolutionary economics research (Sutton, 1997) have indicated that the mortality rate in a population of firms tends to decline with age. Population ecologists have noted the vulnerability of young organizations to selection processes that favor structural inertness, and consequent accountability and reliability. Young, resource-strapped organizations have to internalize and learn new roles as social actors (Hannan & Freeman, 1989). They lack links with external stakeholders (Freeman et al., 1983) and thus find it difficult to attract customers away from established, older organizations. Economists attribute the liability of newness to the costs of information acquisition and to path-dependent (historically determined) organizational learning processes (Geroski, 1995; Jovanovic, 1982). Since the accumulation of competitive resources and capabilities happens over time, age is positively related to survival.

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for deviating from existing norms. Thus, these entrants are likely to enjoy greater latitude in what they do to survive. Further, the growth phase provides the entrepreneurial opportunity to create and restructure interfirm relationship networks (Madhavan et al., 1998), which can serve as strategic resources in buffering the risks associated with youth and in compensating for the disadvantages of inexperience (Baum & Oliver, 1991). Thus, peripheral, relatively nonempowered firms have the opportunity and ability to initiate structure-loosening events (Burt, 1992) and, in doing so, can benefit disproportionately more than older firms (Henderson & Clark, 1990; Madhavan et al., 1998).

During the mature phase, however, institutional structures are crystallized, norms are set, and the dominant design has emerged. Well-established performance parameters penalize young entrants that are either unreliable or that fail in their accountability. The incremental, process-oriented innovations that typically characterize this phase help sustain the performance trajectory of a product class and reinforce network structures, which in turn disproportionately benefit older firms. Accordingly, the disadvantages associated with newness are likely to be higher during this phase than at earlier times in the industry's history. Therefore, although Suarez and Utterback (1995) suggested that a possible selection bias in the post-dominant-design era of an industry may actually reduce firms' risk of failure in their early years, we believe that overall, the arguments in favor of less liability of newness during the growth phase are stronger.

Hypothesis 2. The mortality rate of firms in their early years owing to the liability of newness will be lower during the growth phase of their industry than during its mature phase.

Organizational size: The liability of smallness. Empirical findings from evolutionary studies in both ecology (Freeman et al., 1983; Hannan & Freeman, 1984) and economics (see Audretsch, 1997; Dunne, Roberts, & Samuelson, 1989; Sutton, 1997) indicate that mortality rates decline with increased size. In ecology, the liability of smallness thesis stems from the idea that selection processes favor large organizations' structural inertia (Hannan & Freeman, 1977, 1984), access to capital and trained workers (Aldrich & Auster, 1986), and legitimacy with external stakeholders (Baum & Oliver, 1991). In economics, the advantage of size relates to greater market power (Bain, 1956) and minimum efficient scale (Jovanovic, 1982; Mansfield, 1962). However, organization size has also been associated with some detriments. The adaptationist perspective (Child, 1972) suggests that smallness is a virtue in highly uncertain, dynamic environments. Following the development of radically new, competency-destroying technological innovations, large, less flexible, inertia-laden organizations are disadvantaged (Tushman & Anderson, 1986). However, as Barron (1999) argued, such innovations are exceptional events that do not negate the absolute advantage of size, and there is very little evidence that survival is negatively related to size. Further, as Baum and Oliver (1991) noted, the evidence of the effects on failure of organizational transformations made possible by flexibility is mixed. Thus, "bigger is better," since associated advantages are likely to reduce the failure rate among large organizations.

The issue of significance in our time-variant model is whether and how the advantage of size changes over time as an industry evolves. We argue that the degree to which organizational size facilitates survival is likely to be conditioned by the changing competitive conditions accompanying the structural discontinuity in an industry's life cycle. In the growth phase, a large resource base enables a firm to follow multiple technological trajectories, accessed either through internal development or through interorganizational links, thus reducing the hazard relative to a one-technology company. Further, scientific breakthroughs and commercializing technology are different skills and require different sets of resources. Larger firms are better equipped to impact both supply-side and demand-side factors by making resource commitments that enable the development of collateral assets that help build market infrastructure (Teece, 1986), create customer demand in the nascent market, and make the R&D investments necessary to bring down per unit prices (Klepper, 1996). They are also better positioned through their size to influence the standard-setting process. Accordingly, smallness may be a disadvantage during the growth period when the market is in flux. Further, ecology research suggests that structural inertia, or an organization's ability to chart a clear course and stick to it, improves survival chances (Hannan & Freeman, 1984). In a dynamic and uncertain environment, the ability to perform reliably and maintain accountability is likely to be a valuable organizational asset. Therefore, the virtue of the organizational inertia that is associated with size is likely to be more pronounced during the era of ferment, and largeness is likely to be more beneficial during the growth phase.

Although entering small in the growth period may render temporary advantages of flexibility, there is an unequivocal growth imperative, since the basis of competition pits small firms directly
against their larger counterparts. Economists have argued that a major function of entry for a company is to gain a foothold in an industry and, through subsequent learning processes, discover the viability of the ideas and competences upon which the firm was founded. According to Jovanovic (1982), firms typically enter at a small, even suboptimal scale of output and then, if subsequent performance warrants, expand. Successful entrants grow and achieve a minimum efficient size, while weaker firms remain small and are ultimately forced to withdraw if they are unable to reach an optimal scale. The imperative to grow is lower, however, for firms that are already close to minimum efficient scale (Geroski, 1995; Sutton, 1997). The consequences of not growing and suffering from a debilitating cost disadvantage are thus negatively related to size (Agarwal & Audretsch, 2001). Accordingly, the advantage of size is substantial during an industry’s growth period, since empirical regularities indicate a positive relationship between firm size and survival for any given growth rate (Sutton, 1997).

In the mature phase, as we have argued above, the transformation of entry and survival barriers causes all firms, small and large, to face higher mortality rates. However, we believe that the disadvantage of smallness is partially mitigated in this period. All three perspectives indicate a possible shift in the basis of competition owing to increasing market concentration. Although economic models suggest that shakeouts lead to increasing market concentration and thus, possibly, to skewed size distributions, wherein large firms displace smaller ones, they are less illuminating regarding the market dynamics after a shakeout and the emergence of a dual structure in which large and small firms coexist. Notably, though, work by Porter (1979) and Caves and Porter (1977) suggests that particular advantages may accrue to small and specialized entrants who occupy strategic niches ignored by dominant firms during the mature phase. Further, Klepper (1996) argued that small-scale, mature phase entry may be profitable since incumbents have strategic disincentives to exploit all innovative opportunities, or may suffer from inefficiencies due to large size.

This argument is well complemented by ecology models, which on the one hand offer a somewhat imprecise explanation of market concentration, but on the other, provide interesting insights on post-concentration selection processes. According to resource-partitioning theory, large and small firms coexist symbiotically (Freeman & Lomi, 1994; Swaminathan, 1995). The few generalist firms that dominate a market during an industry’s mature phase tend to concentrate on the resources at the market center, allowing specialist firms to enter and exploit peripheral market segments. In fact, the survival chances of small, specialized firms may actually increase since they operate in a very different resource space from dominant incumbents and thus risk little retaliation from their larger counterparts (Swaminathan, 1998). In technology studies, too, there is evidence of coexistence of small and large firms. Baum and his colleagues (1995) argued that inertia often makes it difficult for incumbents to fully exploit enhanced technologies, thus creating opportunities for new entrants to develop specialized assets, market knowledge, and reputation. Accordingly, the basis of competition shifts to a dual competitive structure in which large, concentrated firms compete against each other, leaving small, specialized firms to vie for positions at the periphery. Importantly, this structure reduces the imperative for small firms to grow. Smallness may thus be less of a problem during the mature period, when an industry has concentrated, than it is during the preceding growth period. Therefore,

Hypothesis 3. Smallness will be less of a liability during the mature phase of an industry than during its growth phase.

Organizational strategy: Chronological sequence of entry. Existing research on order-of-entry effects has generally shown that early movers enjoy higher survival rates than later entrants; analyses have indicated both direct effects of order of entry (cf. Kalyanaram, Robinson, & Urban, 1995) and indirect effects, such as favorable responses to marketing mix and product quality (Bowman & Gatignon, 1996). As Lambkin and Day (1989) pointed out, however, although entry and selection processes occur throughout life cycles, most studies have considered only the pioneers and the “fast followers” that typically enter early in the growth phase of the life cycle, rather than all entrants. Shankar, Carpenter, and Krishnamurthi (1999) noted that doing so implies that a firm’s growth rate and marketing effectiveness are independent of the phase of the life cycle in which the firm enters. Their study provides evidence that order-of-entry issues need to be examined in terms of the phase of the life cycle in which entry occurs, in line with prior econometric and marketing studies that report systematic variation in market response parameters during different phases of the life cycle (Levitt, 1965; Winer, 1979). We follow this advice here.

Suarez and Utterback (1995) presented evidence that early entry by a firm vis-à-vis the emergence of
a dominant design results in a higher probability of success. Since dominant designs emerge through a process of experimentation, early entry is argued to allow a firm to buy time to experiment with new products in an era of ferment. Further, early entry relative to the dominant design offers advantages associated with market knowledge, specialized processes, distribution networks, and reputation (Baum et al., 1995). These arguments are reflected in work on first-mover advantage (e.g., Lieberman & Montgomery, 1988) in which it is claimed that early movers can preempt resources—of geography, technology, or customer perception—and thus increase their performance relative to later entrants.

It has also been argued that the failure rate of new firms will be especially high during the years following the transition between life cycle phases (Utterback & Suarez, 1993). This is a consequence of selection pressures that disadvantage new entrants, as the presence of collateral assets and incumbents’ economies of scale present significant barriers to survival for firms that venture to enter an industry. Thus, the period following the emergence of a dominant design is characterized by a wave of exiting firms “made of entrants from the previous period, and new entrants that are either unable to master all aspects of the technology and those unlucky enough to enter following the dominant design” (Suarez & Utterback, 1995: 420). Strong patent positions and established networks combine with the high failure rates during the shakeout period to create a hostile environment for new entrants. Further, the knowledge regime shifts from being entrepreneurial to routinized, which in turn disadvantages new entrepreneurial ventures during this period (Nelson & Winter, 1982; Winter, 1984).

Since the battle for survival during the shakeout is fierce, and scarce resources tend to coalesce around likely winners, entrants early in the mature phase are likely to suffer from a high failure rate. This effect is likely to diminish over time, however, thus increasing the survival rate for later entrants. Baum and his colleagues (1995) argued that standardization reduces uncertainty and stimulates entrepreneurial opportunities that incumbents may be unable to take advantage of because of their inertial tendencies. Further, the resource-partitioning effect that occurs over time creates opportunities for later entrants to carve out strategic niches in a symbiotic relationship with incumbents (Caves & Porter, 1977; Freeman & Lomi, 1994; Klepper, 1996; Swaminathan, 1995). Therefore, among posttransition entrants, later entrants are likely to have an advantage over those that entered early. Thus,

Hypothesis 4. The failure rate will increase with chronological time of entry for growth phase entrants but decrease for mature phase entrants.

Ecological processes: Density dependence. The curvilinear relationship between population density and mortality is theorized to stem from the sequential processes of legitimacy and competition (Hannan & Carroll, 1992; Hannan & Freeman, 1989). Initially, increasing density increases legitimacy at a decreasing rate, during which period the founding rate in a population increases and the failure rate decreases. In the early years of a population, density and the legitimacy of the organizational form are both low. However, competition is also low, since density is far below carrying capacity. Over time, selection pressures become stronger as the population approaches its carrying capacity. Increasing density now increases competition at an increasing rate, with detrimental effects on the failure rate.

The relationship between density and mortality is accordingly posited to be U-shaped. Empirical findings, too, support this curvilinear relationship (see the 1996 review by Baum). Typically, however, tests of density-dependence theory have been based on populations that have evolved well beyond their peak densities. Baum and Powell (1995) criticized this practice and argued that including information from the period of a population’s decline without accounting for the historical and structural changes that accompany evolution confounds results. We responded to this concern about ahistoricism and accounted for temporal heterogeneity in our test of the effect of density dependence on organizational failure.

Although low density in early periods is logically related to an increase in legitimacy, its effect in a market that has already been legitimized is uncertain (Baum & Powell, 1995). Thus, while the quadratic effect of density in growth years is theoretically justified, given a ceiling on the effect of legitimacy and the accelerating effect of competition, it is unclear whether the arguments of either density as proxy (Hannan & Freeman, 1989) or density as process (Hannan & Carroll, 1992) hold in a mature phase. In line with the theoretical rationale, we expected a quadratic relationship between population density and mortality during industries’ growth phases. However, in the mature phase of an industry, since the population has already been legitimized by earlier activity, the implications of low density are quite different. Low-density conditions reflect market concentration and resultant resource partitioning. A few large organizations sur-
vive the shakeout in an industry and establish market power over substantial segments of the market. Increasing concentrations create opportunities for new, specialized entrants who can coexist with the few large generalists. Accordingly, low density during a mature phase would be associated with an increase in survival rate. Accordingly,

Hypothesis 5. Density will have a U-shaped relationship with failure in the growth phase of an industry and a linear relationship with failure in its mature phase.

METHODS

Sample and Data

We used the Thomas Register of American Manufacturers as our source of information on firm entries into and exits from the industries created by the product innovations in our sample, most of which were also studied by Gort and Klepper (1982). The Thomas Register, dating back to 1906, is a comprehensive national buying guide for the full range of products manufactured in the United States (Lavin, 1992: 129), and researchers in economics (and, more recently, those in marketing) have relied on it when studying the diffusion of innovations and market evolution (e.g., Gort & Klepper, 1982; Robinson & Min, 2002). The publisher of the Thomas Register attempts to achieve complete representation of domestic manufacturing by subscribing to a broad range of industry newsletters and looking for start-up ventures in university incubators (for details, see Gort and Klepper [1982] and Klepper and Graddy [1990]).

As did Gort and Klepper (1982), we designated the first year that the industry listing appears in the Thomas Register as the year of commercial introduction of an innovation. The final set of 33 innovations (see Table 2, below) compares favorably in size with those investigated in other historical studies (cf. Sultan, Farley, & Lehman, 1990). The inventory of all firms existing in each industry covered the period from the industry’s initial year of commercialization through 1991. In addition to the names and addresses of firms, the data contain the following firm-specific information: year of entry, year of exit, asset size for each year of operation, and diversification. We also ensured that the entries did not identify firms that had merely been renamed or relocated as new. Identifiable mergers were treated as the continuance of the larger firm and the exit of the smaller firm (Mansfield, 1962). Additionally, we obtained industry-level information on capital intensity from the Census of Manufactures and information on R&D intensity from the National Science Foundation. The final database of firms consists of a total of 3,431 firms pooled across the product innovations, resulting in 38,880 firm-year observations.

Although the study draws from the same pool of industries as the Gort-Klepper study—with two new industries, contact lenses and video cassette recorders, included since they gained prominence after the Gort-Klepper study was published—the data were developed independently, and the time period covered was extended through 1991. In particular, our data set tracks actual firm entries and exits, while the Gort-Klepper study recorded only the number of firms. We note that several of the industries in the earlier study could not be used for new data development for various reasons. Some industries, like nylon, telemeters, computers, and solar batteries, had breaks in consistency either because a listing was missing in the Thomas Register, or substantial changes in industry definition had occurred over the years. Industries like DDT and cryogenic tanks were omitted since their production ceased during our study period (1973–91). Some industries, like streptomycin and penicillin, were combined into broader categories (antibiotics). Finally, a few industries were not included in the analysis owing to time limitations on the development of data.

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3 Gort and Klepper (1982) supplemented the Thomas Register data with other sources for some of their industries. As a result, their year of commercialization sometimes preceded the year an industry was first listed in the Thomas Register. Unlike their study, which used mere counts of firms, our research required detailed data on firm histories so that we could compute gross entries and exits and spans of firm survival. So we could not use their methodology. Since the number of firms that entered in the early years for the few industries for which Gort and Klepper (1982) had additional information is very small, we do not expect our reliance on the Thomas Register for the systematic identification of the year of commercialization to yield substantively different results.

4 Coding firm exits in this manner, while consistent with other studies (Dunne, Roberts, & Samuelson, 1989; Klepper & Miller, 1995; Robinson & Min, 2002), leads to a question: Do all mergers and acquisitions mean firm failure, or do some reflect success? Although competing risks of exits that allow this delineation would be extremely useful, data limitations did not allow us to make this distinction. A check revealed, however, that less than 3 percent of our exits were attributable to identifiable mergers, thus leading us to believe that our substantive results did not vary because of this limitation.
Our data provide several advantages. First, they represent several product innovations, and the histories span almost the entire 20th century (1908–91). This scope lends a potential for generalizability lacking in single-industry studies. Second, the data were obtained from directories and recorded at the time of event occurrence. The data are, hence, objective and do not suffer from the self-report bias encountered in survey-based data. Third, the inventory of firms is complete, since our database includes every entrant, regardless of size, surviving or dead, as long as it entered the relevant industry. Thus, the data on firms do not suffer from the survival bias that typically plagues studies using retrospective data. Fourth, future replication and validation studies are feasible, since our data have been compiled from secondary data sources.

Variables and Measures

**Dependent variable: Firm failure.** For each firm-year observation, our dependent variable, failure, was coded as 1 if the firm exited the market in a given year, and as 0 otherwise.

**Independent variable: Life cycle phase.** Our theoretical framework distinguishes between the growth phase, or the period in an industry’s history from the time of the industry category’s commercialization till the transformation of barriers to entry, and the mature phase, or the subsequent years.
The transformation of barriers to entry should be directly observable in the trends of gross entry rates, as reported by Agarwal and Gort (1996) and by Hannan (1999), who found that gross entries have a large initial rise followed by a period of suppressed entry and a subsequent resurgence; graphically, a large hill would be followed by a flat area and then by a smaller hill. According to Agarwal and Gort (1996) and Hannan (1999), who found that gross entries have a large initial rise followed by a period of suppressed entry and a subsequent resurgence; graphically, a large hill would be followed by a flat area and then by a smaller hill. Accordingly, we used gross entry rates to measure life cycle phase. Using gross entry rates rather than net entry or number of firms (Gort & Klepper, 1982; Klepper & Graddy, 1990) further satisfies the important condition that our measurement of life cycle phases not be functionally related to the dependent variable of interest, firm failure.

The growth phase was measured as the period between commercialization of an industry and the transformation of entry barriers, when entry significantly declines (the peak of the large hill in the gross entry pattern). The mature phase was measured as the period after that point, including the period of suppressed entry and the subsequent resurgence in entry. Specifically, we used the generalized discriminant analysis procedure used by Gort and Klepper (1982) to distinguish between any two consecutive intervals by examining the data on gross entry rates in each industry and determining the delineating year for each industry. Details of this procedure are in the Appendix. Table 2 lists, for each of the 33 industries, the commercialization year (the start of the growth phase) and the year when the mature phase began.

In our sample, the average number of years spent in the growth phase is 27.72 (s.d. = 14.09), and the average number of years in the mature phase is 23.30 (s.d. = 16.62).

As was documented in Gort and Klepper (1982), 27 of the industries in our study clearly exhibited the prototypical pattern in their numbers of firms. Six industries did not exhibit suppressed gross entry and a resulting decline in the number of firms by 1991, the last year of the time period of the study. This deviation may be attributable to the relative recency of their commercial introduction, or to wide variation in the time taken across industries for the transformation of entry barriers. The proportions of firms entering in each period are summarized for each of the 33 industries in Table 2. On the average, 71 percent of all firms entered during a growth phase, 6 percent entered during a period of suppressed entry, and 23 percent entered in a period of resurgence. The results of F-tests strongly validate rejection of a hypothesis of homogeneity of proportion of entry across periods. Thus, gross entry trends are seen to map relatively well onto our theorized model of intensification of entry barriers at a certain point in the industry life cycle. Illustrating the statistics reported in Table 2, Figure 1 shows the trends of gross entry and, additionally, the trends in the number of firms and gross exits in a sample of four industries. All of the series in Figure 1 are standardized so that the values lie between 0 and 1.

For the industries that experienced the mature phase in the time period under study, Figure 1 illustrates that the structural transformation in barriers to entry also manifest themselves as barriers to survival. This is evidenced by the peaks in number of firms and gross exit, both of which occur after the observed peak in gross entry. Figure 1 also shows that, in the time after the shakeout, the stability or slight increase in the number of firms is a consequence not just of a decline in exit rates, but also of a mild resurgence in gross entry.

Firm-level independent variables. Firm-level variables in the analysis included age, size, and order of entry. Age and size of firms are time-varying, and order of entry is a time-invariant founding condition. For each year of a firm’s existence, age was calculated as the number of years since the time of industry entry. To account for...
nonlinear effects of age, we included both age and age squared in the model. Firm size was measured as the asset size listed in the *Thomas Register* for each year of a firm’s existence. Although firm size has been measured in a variety of ways, including number of employees, sales volume, and value of assets, empirical results have demonstrated that these measures provide very similar results (Chandy & Tellis, 2000). Asset size is reported in the *Thomas Register* in categories of current dollar assets. Since the data span over 80 years, we adjusted the data on size for inflation. As is now customary in research, we used the logarithm of

asset size in our analysis.\(^{11}\) Thirty-seven percent of the firms exhibited change in size at least once during their lifetimes, with 28 percent exhibiting overall growth and 9 percent, overall decline. For order of entry, we adapted Suarez and Utterback’s

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\(^{11}\) Subsidiary firms are reported in the *Thomas Register* as differing from parents listed in other industry categories in size, which leads us to believe that the asset size reflects the size of the firm in the relevant industry. Further multi-industry firms were controlled for by the inclusion of a dummy variable for diversification.
For our sample of industries, the peak numbers of firms relating to both demand and technological conditions. The standard deviation of 46.

Capacities as a consequence of inherent characteristics observed range from 11 to 261, with a mean of 49 and a standard deviation of 46.

Industry-level independent variables. Our key industry-level variables of interest relate to contemporaneous density. In a longitudinal study that groups several industry categories, density heterogeneity across industries makes it inappropriate to represent these variables by the raw annual count of the firms competing in an industry. Accordingly, we measured relative density, defining it as the density in a particular year divided by the peak density observed in an industry. The peak density was used as the divisor since it represents the carrying capacity of a market, or the number of firms sustainable in the market given its resource base. Thus, the closer the relative density number is to 1, the more indicative it is of competitiveness and an environment with resource scarcity. To account for nonlinear effects, we used both contemporaneous density and contemporaneous density squared in the model.

Control variables. Our control for diversifying entrants was obtained by consulting the firm index of annual volumes of the Thomas Register in the year preceding a firm's entry into the relevant industry. In view of Barron, West, and Hannan's (1994) criticism of Freeman's (1990) study for treating industry exits by diversified firms the same as failures by single-industry companies, we included the diversification dummy (1 = "diversified," 0 = "otherwise") to control for significant differences between diversifying and de novo entrants.

We controlled for density at founding by using the relative density measure as defined above for the year that a firm entered an industry. Further, differences in cross-sectional technological intensity were measured as the average of the total (company, federal, and other) industrial R&D funds calculated as a percentage of net sales in R&D-performing companies for the 1987 to 1997 period at the three-digit SIC level. We controlled for differences in capital intensity by using the ratio of gross asset value to total employees at the four-digit SIC level. Finally, since we employed panel data across 33 industries for several years, we included industry dummies to control for industry-specific fixed effects, and we lagged entry and exit rates to control for time-varying effects.

Model Specification and Estimation

We tested our hypotheses by examining hazard rates, or the probability of a firm not surviving another year contingent on attaining a particular age. Several discrete and continuous time models are available for the estimation of hazard rates (Allison, 1995). Following earlier studies (Baum & Oliver, 1991; Henderson, 1999), we used a multiplespells formulation with a complementary log-log specification that allows for incorporation of time-varying covariates. To ensure robustness of results, we estimated additional model specifications (probit, logistic, and Cox proportional hazard models). The results were very similar for the different model specifications.

Hypothesis 1 posits an interphase difference between the growth and mature phases of an industry in terms of firms' mortality. The general model used to test this proposition was:

\[ h_{it} = \gamma_1 \text{age}_{it} + \gamma_2 \text{age squared}_{it} + \beta_1 \text{size}_{it} + \theta_1 \text{density}_{it} + \theta_2 \text{density squared}_{it} + \alpha_i \text{mature phase entrant}_i + \eta_i \text{transition phase}_{it} + \varphi C_{it} \]  

Here, \( h_{it} \) represents risk of failure for the \( i \)th firm in period \( t \). \( \text{Age}, \text{size}, \text{density} \) are the independent variables of interest. \( \text{Mature phase entrant} \) is a dummy variable equal to 1 if a firm entered in the mature phase, and \( \text{transition phase} \) is a dummy variable equal to 1 for firm-year observations of a growth phase entrant that are observed in the mature phase. Thus, the transition phase variable al-

13 We also obtained similar results with a labor-based measure for R&D intensity using Hadlock, Hecker, and Gannon's (1991) classification of three-digit SIC industries, which is based on the ratio of R&D personnel to total personnel employed in 1987 in a particular industry.

14 Although a firm may fail at any point in a given year, the data on failure are updated only annually. A multiplespells, complementary, log-log formulation allows continuous time hazard rates to be obtained from discrete time failure data. See Allison (1995) for details.
lowed us to assess the impact of the transition to the mature phase for a growth phase entrant that existed in both phases. Finally, \( C_t \) is a vector of control variables.

To test Hypotheses 2, we employed a subgroup analysis, estimating a model for firms that entered in the growth phase and another for firms that entered in the mature phase. The differences for the growth and mature phases can be ascertained by a simple comparison of the main effects found for the two subgroups. We note that although some of our hypotheses represent conditioning by the contemporaneous phase (size, for instance), others represent a conditioning of phase of founding (such as order of entry). Since only growth phase entrants can potentially be present in both phases, we distinguished between their firm-year observations by classifying them as either growth transition observations or growth transition observations in our subgroup model for entry in a growth phase as follows:

\[
\begin{align*}
\text{h}_{it} &= \gamma_1 \text{age}_{it} + \gamma_2 \text{age squared}_{it} + \beta_1 \text{size}_{it} \\
&\quad \times \text{growth}_{\text{growth}} + \beta_2 \text{size}_{it} \times \text{growth}_{\text{transition}} \\
&\quad + \theta_1 \text{density}_{it} \times \text{growth}_{\text{growth}} + \theta_2 \text{density}_{it} \\
&\quad \times \text{growth}_{\text{transition}} + \nu \text{density squared}_{it} \\
&\quad \times \text{growth}_{\text{growth}} + \theta_4 \text{density squared}_{it} \\
&\quad \times \text{growth}_{\text{transition}} + \lambda \text{order of entry}_{i} + \varphi \text{C(t)}. 
\end{align*}
\]

Equation 2 enables an easy interpretation of the coefficients. For instance, with respect to size, \( \beta_1 \) represents the effects of size on mortality during the growth years for growth phase entrants, and \( \beta_2 \) represents the effect of size for yearly observations of growth phase entrants observed in the mature phase. Similarly, the model for mature phase entrants is:

\[
\begin{align*}
\text{h}_{it} &= \gamma_1 \text{age}_{it} + \gamma_2 \text{age squared}_{it} + \beta_1 \text{size}_{it} \\
&\quad + \theta_1 \text{density}_{it} + \theta_2 \text{density squared}_{it} \\
&\quad + \lambda \text{order of entry}_{i} + \varphi \text{C(t)}. 
\end{align*}
\]

Table 3 summarizes the predictions of each of the hypotheses. Note that Hypothesis 2 predicts a lower liability of newness in the growth phase than in the mature phase. Liability of newness requires that mortality rates decrease with age, or that the highest mortality rates be observed at birth. Following Henderson (1999), we used a conservative approach and required that a relationship hold for a four-year window after birth. Accordingly, support of the hypothesis relied on finding that the slope of the hazard rate function for ages 0 < \( \tau < 4 \) is declining at a significantly higher rate for the mature phase than for the growth phase. Since researchers have modeled the age-mortality relationship nonlinearly (Baum & Oliver, 1991; Henderson 1999), this condition requires that \( \gamma_1 + 2 \gamma_2 \tau \) assume a lower value in the mature phase than in the growth phase for the specified time window.

RESULTS

Table 4 shows the means, standard deviations, and correlations for the key variables. An examination of the correlation matrix reveals, not surprisingly, that the linear and quadratic terms of variables are highly correlated. Further, as would be expected, the order-of-entry variable is highly correlated with both density at founding and the dummy for mature phase entrant.

Table 5 presents three models that test Hypothesis 1. As noted above, each model contained unreported dummy variables for industries as controls for industry fixed effects. Model 1 is the baseline model of control variables and main effects. As have other researchers, we found that larger firms had a lower mortality rate than smaller firms. The
TABLE 3
Summary of Hypotheses and Predicted Effects\(^a\)

<table>
<thead>
<tr>
<th>Hypotheses</th>
<th>Predicted Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis 1. Firms will have a lower mortality rate during the growth phase of their industry than during its mature phase.</td>
<td>(\alpha_1 &gt; 0; \eta_1 &gt; 0) (\beta_1 &lt; 0; \eta_1 &gt; 0) (\gamma_1 + 2\gamma_2 \tau &gt; 0) for (\tau &lt; 4)</td>
</tr>
<tr>
<td>Hypothesis 2. The mortality rates of firms in their early years (owing to the liability of newness) will be lower during the growth phase of their industry than during its mature phase.</td>
<td>(\gamma_1 + 2\gamma_2 \tau &gt; 0) for (\tau &lt; 4) (\gamma_1 + 2\gamma_2 \tau &gt; 0) for (\tau &lt; 4)</td>
</tr>
<tr>
<td>Hypothesis 3. Smallness will be less of a liability during the mature phase of their industry than during its growth phase.</td>
<td>(\beta_1 &lt; 0; \beta_2 \geq 0) (\beta_1 \geq 0) (\lambda_1 &gt; 0) (\lambda_1 &lt; 0)</td>
</tr>
<tr>
<td>Hypothesis 4. The failure rate will increase with chronological time of entry for growth phase entrants but decrease for mature phase entrants.</td>
<td>(\lambda_1 &gt; 0) (\lambda_1 &lt; 0)</td>
</tr>
<tr>
<td>Hypothesis 5. Density will have a U-shaped relationship with failure in the growth phase of an industry and a linear relationship with failure in its mature phase.</td>
<td>(\theta_1 &lt; 0, \theta_1 &gt; 0 \theta_2 + \theta_1 + 2\theta_2 n &gt; 0, \forall n)</td>
</tr>
</tbody>
</table>

\(^a\) From Equation 1, \(h_{it} = \gamma_1 \text{age}_{it} + \gamma_2 \text{age squared}_{it} + \beta_1 \text{size}_{it} + \theta_1 \text{density}_{it} + \theta_2 \text{density squared}_{it} + \alpha_1 \text{mature phase entrant}_{it} + \eta_1 \text{transition phase}_{it} + \varphi(t)\).

\(^b\) From Equation 2, \(h_{it} = \gamma_1 \text{age}_{it} + \gamma_2 \text{age squared}_{it} + \beta_1 \text{size}_{it} \times \text{growth}_{it} + \beta_2 \text{size}_{it} \times \text{transition}_{it} + \theta_1 \text{density}_{it} \times \text{growth}_{it} + \theta_2 \text{density squared}_{it} \times \text{growth}_{it} + \theta_3 \text{density squared}_{it} \times \text{transition}_{it} + \lambda_1 \text{order of entry}_{it} + \varphi(t)\).

\(^c\) From Equation 3, \(h_{it} = \gamma_1 \text{age}_{it} + \gamma_2 \text{age squared}_{it} + \beta_1 \text{size}_{it} + \theta_1 \text{density}_{it} + \theta_2 \text{density squared}_{it} + \lambda_1 \text{order of entry}_{it} + \varphi(t)\).

\(^d\) We note that our test of Hypothesis 2, in the subgroup framework, is a sufficient but not a necessary condition for \(\gamma_1 + 2\gamma_2 \tau\) to assume a lower value for the mature phase than the growth phase for the specified time window. A similar rationale also holds for our test of Hypothesis 3.

### TABLE 4
Means, Standard Deviations, and Correlations of Key Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>s.d.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Firm mortality</td>
<td>0.94</td>
<td>0.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2. Firm size</td>
<td>6.24</td>
<td>1.38</td>
<td>.03</td>
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<tr>
<td>3. Firm age</td>
<td>11.54</td>
<td>10.67</td>
<td>.03</td>
<td>.10</td>
<td></td>
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<td></td>
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<tr>
<td>4. Firm age squared</td>
<td>247.07</td>
<td>482.39</td>
<td>.03</td>
<td>.08</td>
<td>.91</td>
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<tr>
<td>5. Density</td>
<td>0.69</td>
<td>0.23</td>
<td>-0.01</td>
<td>-0.04</td>
<td>-0.05</td>
<td>-0.3</td>
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<tr>
<td>6. Density squared</td>
<td>0.54</td>
<td>0.29</td>
<td>-0.01</td>
<td>-0.04</td>
<td>-0.07</td>
<td>-0.05</td>
<td>.98</td>
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<tr>
<td>7. Order of entry</td>
<td>-0.59</td>
<td>0.95</td>
<td>-0.03</td>
<td>-0.10</td>
<td>-0.32</td>
<td>-0.30</td>
<td>.22</td>
<td>.19</td>
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<tr>
<td>8. Density at founding</td>
<td>0.56</td>
<td>0.28</td>
<td>-0.10</td>
<td>-0.26</td>
<td>-0.24</td>
<td>.38</td>
<td>.35</td>
<td>.58</td>
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<tr>
<td>9. Life cycle phase</td>
<td>0.21</td>
<td>0.41</td>
<td>-0.02</td>
<td>-0.05</td>
<td>-0.20</td>
<td>-0.15</td>
<td>.02</td>
<td>.002</td>
<td>.61</td>
<td>.21</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>10. Transition from growth to mature</td>
<td>0.32</td>
<td>0.47</td>
<td>-0.001</td>
<td>.07</td>
<td>.50</td>
<td>.39</td>
<td>-0.001</td>
<td>-11</td>
<td>-0.04</td>
<td>.09</td>
<td>-0.36</td>
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<tr>
<td>11. Diversifying entrant</td>
<td>0.65</td>
<td>0.48</td>
<td>.02</td>
<td>.21</td>
<td>-0.05</td>
<td>-0.08</td>
<td>.03</td>
<td>.03</td>
<td>.06</td>
<td>.08</td>
<td>-0.05</td>
<td>.09</td>
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<tr>
<td>12. Lagged entry rate</td>
<td>0.11</td>
<td>0.21</td>
<td>-.004</td>
<td>-.002</td>
<td>-.18</td>
<td>-.10</td>
<td>-.10</td>
<td>-.07</td>
<td>-.14</td>
<td>-.19</td>
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<td>-.20</td>
<td>-.001</td>
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<tr>
<td>13. Lagged exit rate</td>
<td>0.06</td>
<td>0.06</td>
<td>-.03</td>
<td>.005</td>
<td>.02</td>
<td>.01</td>
<td>-.08</td>
<td>-.09</td>
<td>.04</td>
<td>.09</td>
<td>.04</td>
<td>.07</td>
<td>.01</td>
<td>-.01</td>
<td></td>
<td></td>
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<tr>
<td>14. R&amp;D intensity</td>
<td>6.06</td>
<td>4.22</td>
<td>-.001</td>
<td>.04</td>
<td>-.06</td>
<td>-.09</td>
<td>.07</td>
<td>.07</td>
<td>-.002</td>
<td>.12</td>
<td>-.10</td>
<td>.14</td>
<td>.10</td>
<td>.01</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>15. Capital labor ratio</td>
<td>0.61</td>
<td>0.49</td>
<td>.02</td>
<td>.08</td>
<td>.06</td>
<td>.04</td>
<td>.07</td>
<td>.07</td>
<td>-.11</td>
<td>.05</td>
<td>-.08</td>
<td>.15</td>
<td>.10</td>
<td>-.05</td>
<td>-.06</td>
<td>.28</td>
</tr>
</tbody>
</table>

coefficients of age, age squared, and density are insignificant. Among the control variables, diversifying firms have a lower mortality rate than non­
diversifying firms, and lagged exit rates increased mortality rate. R&D intensity, capital intensity, and lagged values of entry rates do not have a significant effect on mortality rate. In model 2, we introduced the life cycle phase of entry. Entrants in the mature phase have significantly higher mortality rates than entrants in the growth phase. In model 3, we further introduced the transition variable that delineates the passage of growth phase entrants into the mature phase. Model 3 shows that not only do mature phase entrants have higher mortality rates than growth phase entrants, but also that growth phase entrants, upon an industry's transition into the mature phase, experience significantly higher mortality rates. Taken in conjunction, these
TABLE 5
Results of the Test of Hypothesis 1: Main Effect of Life Cycle Phase on Firm Mortality

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-2.36** (0.29)</td>
<td>-2.34** (0.29)</td>
<td>-2.15** (0.29)</td>
</tr>
<tr>
<td>Mature phase entrant</td>
<td>0.19** (0.06)</td>
<td>0.37** (0.07)</td>
<td>0.38** (0.07)</td>
</tr>
<tr>
<td>Transition from growth to mature</td>
<td>0.003 (0.01)</td>
<td>0.01 (0.01)</td>
<td>0.01 (0.01)</td>
</tr>
<tr>
<td>Age</td>
<td>-0.0002* (0.00)</td>
<td>-0.0003* (0.00)</td>
<td>-0.0002* (0.00)</td>
</tr>
<tr>
<td>Age squared</td>
<td>-0.05** (0.02)</td>
<td>-0.05** (0.02)</td>
<td>-0.05** (0.02)</td>
</tr>
<tr>
<td>Density</td>
<td>-1.11* (0.50)</td>
<td>-1.21* (0.51)</td>
<td>-1.57** (0.51)</td>
</tr>
<tr>
<td>Density squared</td>
<td>0.88* (0.39)</td>
<td>0.97* (0.39)</td>
<td>1.37** (0.40)</td>
</tr>
<tr>
<td>Diversifying entrant</td>
<td>-0.15** (0.05)</td>
<td>-0.15** (0.05)</td>
<td>-0.16** (0.05)</td>
</tr>
<tr>
<td>Density at founding</td>
<td>0.66* (0.09)</td>
<td>0.62* (0.09)</td>
<td>0.41* (0.10)</td>
</tr>
<tr>
<td>Lagged entry rate</td>
<td>0.09 (0.10)</td>
<td>0.11 (0.09)</td>
<td>0.14 (0.09)</td>
</tr>
<tr>
<td>Lagged exit rate</td>
<td>1.45** (0.33)</td>
<td>1.45** (0.33)</td>
<td>1.43** (0.33)</td>
</tr>
<tr>
<td>R &amp; D intensity</td>
<td>-0.01 (0.03)</td>
<td>-0.01 (0.03)</td>
<td>-0.01 (0.03)</td>
</tr>
<tr>
<td>Capital labor ratio</td>
<td>-0.46 (0.30)</td>
<td>-0.56* (0.30)</td>
<td>-0.69* (0.30)</td>
</tr>
</tbody>
</table>

Values are unstandardized regression coefficients, with standard errors in parentheses.

*p < .01

**p < .05

findings make it evident that firms in the growth phase have lower mortality rates than firms in the mature phase, thereby supporting Hypothesis 1.

Table 6 presents the results of our subgroup analysis. Models 1 and 2 show the results for entrants in the growth phase, and model 3 displays the results for entrants in the mature phase subgroup. Since the variables for order of entry and density at founding were highly correlated for the growth phase, we estimated two different models incorporating order of entry (model 1) and density at founding (model 2) separately. The results for the two models are similar.

18 The high correlation of order of entry and density at founding reported in Table 4 is attributable to the growth rather than the mature phase. Although the correlation between order of entry and density at founding is .63 in the growth phase, it is -.05 in the mature phase. This is consistent with the observed trends in the number of firms.
For growth phase entrants, the coefficients of age and age squared are insignificant, indicating that these firms do not suffer from a liability of newness. However, for firms entering an industry in the mature phase, the coefficient of age is negative and significant, and that of age squared is insignificant. These coefficients indicate that mature phase entrants experience the highest mortality rates at birth and a declining hazard rate function thereafter. These results thus support the hypothesis, since taken together they imply that firms entering in the growth phase of an industry do not suffer from a liability of newness, but firms entering in the mature phase do.

With respect to the liability of smallness, increase in size improves survival probability for growth phase entrants during the growth phase years, but not during the mature phase years. Further, size is not significant for mature phase entrants. Together, these results indicate that the liability of smallness affects only growth phase entrants during the growth phase, thus supporting Hypothesis 3.

For growth phase entrants, order of entry is positive and significant, implying that entering later during the growth period significantly increases the likelihood of mortality. For mature entrants, order of entry is negative and significant, implying that entering later during the mature period significantly decreases mortality rate. Thus, early entry helps entrants’ chances of survival in the growth phase but hurts it during the mature phase, thereby supporting Hypothesis 4.

The coefficients of density and density squared are, respectively, negative and positive for growth phase entrants during the growth phase years, implying a U-shaped curve. However, these coefficients are insignificant for growth phase entrants that transitioned into the mature phase. For mature phase entrants too, the coefficients of density and density squared are negative and positive respectively, implying a U-shaped curve. Thus, we find partial support for Hypothesis 5. The hypothesized U-shaped relationship holds in the growth phase. However, in the mature phase, where we had predicted a linear effect, we find either no effect on mortality (for growth phase entrants that survive into the mature phase), or a strong U-shaped relationship (for mature phase entrants).

**Robustness of Results**

We tested several additional models to ascertain the robustness of our results. First, we performed numerous tests to ascertain that the results were not sensitive to the classification of the in-between years as in either the growth or mature phase by systematically choosing each of these years as the year separating the mature phase from the growth phase. Second, the years at the start of the mature phase are characterized by very low entry and also strongly correlate to the shakeout years (e.g., Klepper & Graddy, 1990). To test if our measurement might be sensitive to the characteristics of entrants in the zero- to low-entry period, we adopted an extreme measure by dropping these firms from the analysis. There were no significant differences in the results. This is not surprising, since the firm-year observations for the period of zero to low entry constitute less than 5 percent of the entire sample. Third, six industries that did not see a mature phase were removed from the analysis, and results were reestimated. Results were similar to those obtained with their inclusion, indicating that our results were robust.

**DISCUSSION AND CONCLUSION**

Time conditions. Time changes the rules of the game. Time impacts existing precepts and makes a subtle mockery of static tenets. Time is endemic, and its effects are ubiquitous. Therefore, it is vital to incorporate the systematic and fundamental effects of time in evolutionary studies. With this objective in mind, we integrated theories, insights, and empirical findings across three influential bodies of research on industrial evolution to predict and test the time-varying effects of certain key theoretical precepts using a range of industries extant during the 20th century. Understanding how temporal changes in an industry affect the survival of constituent organizations is of central concern in organizational ecology, evolutionary economics, and technology management research.

This study was prompted by the belief that evolutionary changes in competitive conditions not only directly impact organization survival, but also cause time-varying relationships between firm and environmental characteristics and survival. By adopting a conditioning view of time, our research gets to the heart of the ahistoric criticism that quite ironically plagues evolutionary research. We integrated theoretical insights from ecology, evolutionary economics, and technology management research to focus on a phenomenon of central interest to evolutionary researchers, namely, life cycle phases. Although theoretical rationales differ, we identified a common underlying theme: the transformation of entry barriers at one point in time during an industry's evolution leads to irrevocable changes in the competitive landscape. Empirically, this is witnessed by a sharp decline in gross rates of
entry into the industry at a certain point in time. We distinguished between the growth and mature phases of an industry on the basis of gross entry patterns and examined the effects of this transition on firm survival (Hypothesis 1). We then examined the conditioning effect of life cycle phases on organizational demographics, firm-level strategy, and ecological processes (Hypotheses 2–5). In doing so, we revisited certain central tenets in evolutionary research and questioned existing wisdom surrounding their universal application in populations across time.

In general, our results strongly support the thesis that the irrevocable transformation of the competitive landscape affects not just mortality rates, but also the nature of the relationships between various theorized organizational and industrial characteristics and environmental processes and failure rates. Our findings on the main effect of life cycle phase are consistent with prior literature. Mature phase entrants suffer from significantly higher levels of mortality than growth phase entrants (Agarwal & Gort, 1996; Klepper, 1996; Suarez & Utterback, 1995) and, further, growth phase entrants that make the transition into the mature phase face elevated levels of mortality as well. The distinct survival advantage in the growth phase seems related to a more favorable knowledge regime for entrepreneurial entry along with less formidable scale and resource barriers during this era.

Our contingency tests shed new light on age and size dependence, central precepts in both ecology and industrial economics research. Our findings on early-year firm mortality clearly support our predictions that disadvantages associated with newness are mitigated by a favorable knowledge regime during the growth phase but are reinforced during the mature phase. Therefore, although newness does not hurt in the early phase, the advantages associated with age clearly accrue during the mature phase. Our findings thus resonate with those of researchers who have argued that multiple patterns of age dependence may simultaneously exist within a single population (Baum, 1996; Henderson, 1999).

Regarding size, we found support for the structural inertia view. Largeness enhances firms’ ability to shield themselves from uncertain winds of change during the growth phase, thereby reducing mortality rates. While all firms, small and large, benefit from lower mortality rates in the growth phase, the disadvantage of smallness is exacerbated during the growth phase. During this period, small firms face an imperative to grow, since they have to directly compete with larger firms with “deep pockets” in developing crucial marketing infra-

structure, interfirm networks, and new industries (Schoonhoven, Eisenhardt, & Lyman, 1990). For the concentrated mature phase, however, our findings support the resource partitioning and strategic niche arguments. Scale gives the advantage to large firms during the mature phase, but increasing concentration partitions the market in such a way that small, specialized firms occupy the periphery of the resource space and coexist with larger firms that occupy the center of the resource space. Small firms combat their size disadvantage by occupying strategic niches and fulfilling demands left unmet by larger firms with a more standardized product. Accordingly, size does not pose a threat to the survival of small firms simply because their interdependence with larger firms assumes a noncompetitive aura.

Our findings on chronological order of entry indicate that early entry during the growth phase helps survival but is disadvantageous during the mature phase. Our evidence also supports elevated mortality rates for entrants in the years just prior to and immediately after the transition from growth to the mature phase, when barriers to entry are intensifying. Our findings on chronological order of entry during the growth years are thus consistent with Suarez and Utterback’s findings (1995) in that we also found that the earlier a firm enters an industry vis-à-vis the phase-to-phase transition, the higher its probability of survival. However, our findings for mature phase entrants indicate that the later a firm enters the industry vis-à-vis the transition, the higher its probability of survival. Suarez and Utterback (1995) hypothesized to the contrary but reported an “ambiguous effect.” Our study therefore provides insights that may help resolve this issue.

Our finding that density has a U-shaped relationship with mortality during the growth phase supports the density-dependence theory. Baum and Powell voiced a concern that findings from numerous studies that support this theory may be “undermined by the incorporation of information on the decline of the population, which density dependence theory is not designed to explain” (1995: 533). Therefore, our finding the U-shaped relationship between density and mortality in the period prior to the peaking of a population provides a more theoretically grounded test of the theory as well as resounding support for it. However, the similar U-shaped relationship observed during the mature period is intriguing and difficult to interpret. We offer two speculations. First, we speculate that there is no linear time trend in density during the mature phase owing to the initial shakeout and subsequent resurgence in the number of firms. Accordingly, similar levels of density during shakeout
and resurgence may confound results. Second, market concentration during the mature phase makes a number count of density problematic (Baum, 1996). Our results thus provide renewed support for Baum and Singh’s (1994) call for alternate measures and tools for incorporating historical and evolutionary processes of legitimation and competition into future model-testing efforts.

Although our study contributes to the dialogue between diverse literatures by identifying the complementarities and commonalities of underlying selection mechanisms, additional research is needed to diagnose the relative strengths of various forces in individual industries. For example, is dominant design a more important force than resource constraints or depletion of technological opportunities? It may well be that industry characteristics condition the relative importance of underlying selection mechanisms. Also, it is of value to investigate factors contributing to the variance in the speed with which different industries reach maturity and how this affects the advantage of incumbency. Future research also needs to explore the contingent impact of time on how additional strategic choices impact organizational mortality, and additional measures of performance, such as sales, market share, and growth. For example, speed to market (Schoonhoven et al., Lyman, 1990) could be more important during growth than mature periods. Further, data limitations prevented us from studying whether the effects of different forms of diversification (related versus unrelated) vary over the life cycle. Among de novo entrants, an associated issue is the conditioning effect of time on the transfer of knowledge from incumbent businesses to their spin-offs through employee mobility. A question of interest here is whether entrants originating from firms in populations being destroyed by new industries have a greater impact on “creative destruction” in the early years of evolution than entrants from unrelated markets or de novo entrants. The emergence of a new market and its maturation into a stable state both herald a new time in the context of the competitive landscape. By bringing attention to the direct and contingent effect of time, we hope that our research, by capturing lessons from innovations during the last century, sheds light on the future that beckons during the new century.

REFERENCES


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**APPENDIX**

**Generalized Discriminant Procedure Used to Identify Growth and Mature Phases in the Industry Life Cycle**

To distinguish between the growth and mature phases, we examined the data on annual gross entry rates for each industry, which typically could be graphed to show a large peak separated from a smaller peak by a flat area representing a period of no or low entry. (Agarwal & Gort, 1996; Hannan, 1999.) To determine the breakpoint year for each industry, we first partitioned the series into three categories; the first two categories represented the years in which gross entry rate clearly reflected the growth and mature phases, respectively. The series of \( T \) consecutive in-between years comprising the third category are then labeled \( x_1, x_2, \ldots, x_T \). The problem is then to choose an optimal dividing year \( j \) so that observations \( x_1, x_2, \ldots, x_j \) are classified as in the growth phase and \( x_{j+1}, x_{j+2}, \ldots, x_T \) are classified as in the mature phase. This can be accomplished using the following three-step procedure:

1. For each \( j = 1, 2, \ldots, T \), we computed

\[
d_1(j) = \sum_{i=1}^{j} \frac{x_i}{j} \quad (A1)
\]

\[
d_2(j) = \sum_{i=j+1}^{T} \frac{x_i}{T-j} .
\]

2. The choice of the dividing year was limited to those values of \( j \) for which

\[
|d_1(j) - \mu_1| \leq |(\mu_1 - \mu_2)/2| \quad (A2)
\]

\[
|d_2(j) - \mu_2| \leq |(\mu_1 - \mu_2)/2| ,
\]

where \( \mu_1 \) and \( \mu_2 \) represent the mean rates of gross entry for the growth and mature categories. If there were no values of \( j \) satisfying Equation A2, then all observations were placed in the growth phase, if \( |d_1(T) - \mu_1| < |d_2(T) - \mu_2| \), and in the mature phase otherwise. The rationale behind this step was that the mean of the observations classified as in each of the two phases is closer to the sample mean of the observations initially put into those phases than in the alternative phase.

3. If multiple values of \( j \) satisfied Equation A2, then we selected the value of \( j \) from this set that maximized \( |d_1(j) - d_2(j)| \). This step ensured that, among the classifications that would satisfy step 2, the classification that was chosen maximized the difference between the means of the points placed into the two alternative phases.

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