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Technology and Industry Evolution

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THE LIFE CYCLE PHENOMENON

Scholars across a range of disciplines have found the life cycle metaphor useful in describing the evolution of industries. Subsequent to the first commercialization of a product, industries are seen to go through a progression that has substantial regularities in the time trends of key variables, such as number of firms, sales, price, and innovation patterns. Although life cycle models apply to a broad range of settings, our focus in this chapter is on the relationship between technological and industry evolution, two processes that we posit are inextricably linked. We begin by developing stylized observations about technology and industry development – that is, a generic industry life cycle model, building on empirical work from three areas of the literature: technology management, evolutionary economics, and organizational ecology. We then compare and contrast these literatures and finally propose a future research agenda motivated by this comparison.

For purposes of exposition, we distinguish three stages of evolution – emergence/growth, shakeout, and maturity[1] – to describe the basic model put forth in the literature (Table 1.1). In the initial stage, high levels of uncertainty permeate every aspect of an industry. Firms experiment with a variety of technologies, since the performance trajectory of different technologies is unclear. Customers have undeveloped preferences and explore a range of product uses. The market is small and production processes are not specialized, so manufacturing is inefficient. Some industries never progress beyond emergence, but those that do generally experience

[1]These three stages are roughly equivalent to what evolutionary theorists label 'variation, selection, and retention'; what Utterback and Abernathy (1975) label 'fluid, transitional, and specific'; and what Klepper and Graddy (1990) call 'growth, shakeout, and stabilization'.

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TABLE 1.1 Stylized facts related to the stages in the industry life cycle.

Emergence/growth stage	*Shakeout stage*	*Mature stage*
Inception of industry due to initial commercialization of an invention. Other words used to describe this stage, such as *fragmentation, fluid phase, variation, era of ferment, and entrepreneurial regime* reflect that this stage is characterized by	Transition occurs due to establishment of efficiencies in production, dominant design, and ensuing competitive pressures. Other words used to describe this stage include *selection and transitional phase.* This stage is characterized by	Transition occurs when an 'equilibrium' number of firms has been reached. Other words used to describe this stage include *retention, specific phase, era of incremental change, and routinized regime.* This stage is characterized by
◆ very few firms initially, followed by rapid entry by firms, both entrepreneurial and diversifying entrants with pre-entry capabilities;	◆ rapid decline in the number of firms from the peak, as inefficient firms exit due to increased competitive pressures;	◆ stable number of firms, with low levels of both entry and exit rates relative to the other stages of the life cycle;
◆ high technology and demand uncertainty;	◆ establishment of a dominant design;	◆ reduction in overall innovation rates relative to the earlier stages, with most innovations being incremental in nature;
◆ experimentation with different approaches and product design;	◆ increasing emphasis on process relative to product innovation;	◆ innovation conducted by large, established firms, which focus on economies of scale;
◆ emphasis on both product and process innovation, with the relative ratio of product to process innovation decreasing over the stage;	◆ innovation conducted by large, established firms, which focus on economies of scale;	◆ leveling off in the growth rate of sales, as industry reaches high penetration rates;
	◆ decrease in the growth rate of sales;	

◆ very low levels of initial sales, and sustained growth in output over the entire period; ◆ decrease in price, particularly when adjusted for quality; ◆ gradual development of complementary assets (e.g., distribution channels, supply chain relationships, related infrastructure). There is wide variation across industries in the number of years that is characterized as the emergence/growth stage, with some products never progressing beyond the emergence stage.	◆ continuing decline in prices, particularly when adjusted for quality. There is wide variation in industries in the number of years and severity of shakeout in the number of firms.	◆ stable price levels; ◆ well-established complementary assets. There is wide variation in industries in the number of years and the 'equilibrium' number of firms that exist in the mature stage. Transition to a decline or a cycle back to the Emergence Stage may occur due to new (radical) innovations being introduced

rapid growth as the new technology diffuses across a set of consumers. The growth in the industry manifests itself in the form of increasing sales, an increasing number of firms, and declining price, particularly when price is adjusted for quality improvements. Quite salient is the entry by all types of firms, including entrepreneurial start-ups and entrants diversifying from related industries. In addition, high levels of product innovation characterize this stage, although the relative rate of process innovation increases over time.

The transition to the shakeout stage occurs because of the establishment of production efficiencies and the standardization of product designs, a process that leads to a dominant model. On the demand side, as users become more familiar with the industry's products, their preferences stabilize, and product variety decreases. Thus, this stage is characterized by an increasing emphasis on process innovation relative to product innovation, and an increasing share of the innovation stems from large, established firms that focus on efficient mass production. The competitive pressures unleashed in consequence of economies of scale, and specialized manufacturing processes that increase efficiency, result in a rapid decline in the number of firms. The rate of change in sales and price begins to decline towards the end of this stage, though output generally increases, and prices continue to fall, particularly when adjusted for quality.

During the mature phase of the industry, growth slows, and the technological and competitive environments are relatively stable. This stage is characterized by a stable number of firms. Although entry and exit of firms occur and are positively correlated, these rates are lower than they are in the other stages of the industry life cycle. Similarly, although some product and process innovation takes place, most of the innovations are incremental. The industry exhibits stable prices, level sales growth, and a well-established infrastructure supporting its activities.

Finally, industries in periods of stability may either transition into decline or spiral back into emergence as the result of disruptions by discontinuous technological change. This cycle may repeat multiple times as waves of discontinuous technological change invade an industry over time.

Underlying this stylized description is a wealth of empirical research that has documented a broad range of empirical regularities. We review the findings of three distinct literatures that have addressed technology and industry evolution: technology management, evolutionary economics, and organization ecology. We then explore the differing explanations for the observed regularities, comparing and contrasting these three literatures. Finally, we conclude with a discussion of outstanding research questions in this line of inquiry.

Empirical Regularities

Empirical regularities in the technology management literature: patterns of technological and industry evolution

The technology life cycle literature is motivated by the premise that evolutionary changes in technology underlie the development of many new industries. Understanding patterns of technological change over time is therefore an important component of understanding competition. Empirical studies in this domain tend to be longitudinal, tracking the technological and competitive progress of a single industry or of a small set of industries over extended time periods. Empirical regularities become evident when we examine the patterns of technological change that accompany the stages of industry evolution; Table 1.2 summarizes these change patterns.

Innovative activity. In the nascent stage of most industries, technical variety is high, with a diverse set of innovations embodied in a range of competing products. Product artifacts look different, incorporate fundamentally different core technologies, emphasize different functions, and offer different features. This phenomenon is well documented. In early automobiles, steam and electric engines, along with the eventually dominant internal combustion engine, were present; the now ubiquitous round steering wheel competed with a joystick-type tiller for controlling the direction of a vehicle; and some cars had three wheels instead of four (Abernathy, 1978; Basalla, 1988). In another example, early radio transmitters used alternator, arc, and vacuum tube technologies before vacuum tubes became dominant (Aitken, 1985; Rosenkopf and Tushman, 1994). In typesetters, over 170 diverse designs were originally developed, including 'cold metal' machines that used pre-cast letters and 'hot metal' machines that cast entire lines of text as an operator typed (Tripsas, 1997b). Airplane landing gear between 1928 and 1933 included not only retractable designs, which eventually dominated, but also many types of fixed landing gear, including unstreamlined versions and 'trouser' streamlined versions with casings that covered the wheels for better aerodynamics (Vincenti, 1994). In many cases, different firms, or communities of firms, proactively introduce and push the adoption of particular technical variants. Examples of this type of competition include AC versus DC power distribution systems (David, 1992), full flight versus flight training device flight simulators (Rosenkopf and Tushman, 1998) and VHS versus beta video standards (Cusumano, Mylonadis, and Rosenbloom, 1992).

Two key studies have explicitly measured technical variety across stages of the technology life cycle. Anderson and Tushman (1990) analyzed technological change in the portland cement, minicomputer, and glass-manufacturing industries, identifying technological discontinuities, periods of ferment, dominant designs, and periods of incremental change. Within each industry, they then compared the number of new designs introduced during periods of ferment as opposed to eras of incremental change, finding that in three of four comparisons significantly more designs were introduced during the period of ferment. Second, in their longitudinal study of the development of cochlear implants, Van de Ven and Garud (1993) developed a chronological list of 771 significant events, covering the history of the industry from 1955 to 1989. They classified these events into three categories:

- variation events, which created technical novelty;
- selection events, which created or modified institutional rules (rules that narrowed the range of technical solutions considered);
- retention events, which followed existing rules.

TABLE 1.2 Technology management: empirical regularities in patterns of technological evolution.

Key studies	*Sample*	*Innovative activity over the life cycle*	*Does a dominant design emerge?*	*Are there subsequent technological discontinuities*	*Number of firms, entry and exit over the life cycle*
Utterback and Abernathy (1975)	567 commercially successful innovations from 5 industries	Product innovation starts high and decreases; process innovation increases over time	n/a	n/a	n/a
Abernathy (1978)Abernathy and Clark (1985)	Automobile industry 1900–1970s	High level of product variety early, decreasing over time; process innovation increases over time	Yes; the internal combustion engine, closed body vehicle	n/a	An inverted U-shaped curve for the number of firms in the industry over time
Aitken (1985)	History of radio transmission	Early competition among alternator, arc, and vacuum-tube transmitters	Yes; vacuum tube transmitters	Yes: transistor	n/a

Tushman and Anderson (1986)Anderson and Tushman (1990)	Minicomputer, cement, airline, and glass industries from birth through 1980.	New product designs are more prevalent during an era of ferment than an era of incremental change	Yes; dominant designs observed in all three industries	Yes: a series of discontinuities, characterized as competence-enhancing or competence-destroying	Initially entry exceeds exit; after competence-enhancing change, exits exceed entry, except for minicomputers
Van de Ven and Garud (1993, 1994)Garud and Rappa (1994)	Cochlear implants 1955–1989	Early competition between single and multi-channel devices; technical variation events occurred early in the life cycle	Yes; multi-channel cochlear implants	n/a	n/a
Vincenti (1994)	Airplane landing gear in the first half of the 1930s	Early variety including retractable and fixed (unstreamlined, pants, and trouser) landing gear	Yes; retractable landing gear	n/a	n/a

(*continued overleaf*)

TABLE 1.2 (*continued*)

Key studies	*Sample*	*Innovative activity over the life cycle*	*Does a dominant design emerge?*	*Are there subsequent technological discontinuities*	*Number of firms, entry and exit over the life cycle*
Rosenkopf and Tushman (1998)	Flight simulators	Early competition between variants; community network structure varies across technology life cycle	Yes: full flight simulation standard	Yes	n/a
Murmann (2003)	Synthetic dyes		Yes		An inverted U-shaped curve for the number of firms over time, but the timing varies by country
Tripsas (2008)	Typesetter industry 1886–1990	Highest technological variation during eras of ferment	Yes: hot metal linecaster	Yes: three subsequent waves of technology, driven by preference discontinuities	An inverted U-shaped curve for the number of firms over time, with a new curve for each technological generation

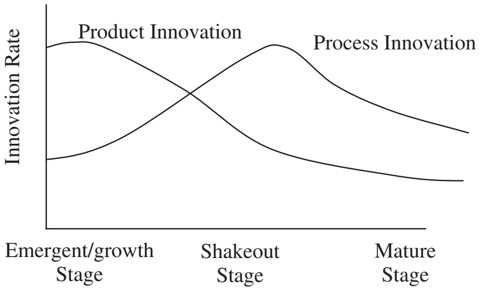

FIGURE 1.1 Relative importance of product as opposed to process innovation over the course of the industry life cycle.

Source: Adapted from Abernathy and Utterback (1978)

The distribution of these events over time showed that technical variation events occurred earliest and exceeded the other two categories until 1983, when the industry began to expand; furthermore, the establishment and reinforcement of institutional rules and routines supported that expansion.

Studies have also documented the relative importance of product as opposed to process innovation over the course of the industry life cycle and found a pattern similar to the stylized depiction of Figure 1.1. Utterback and Abernathy (1975) used Myers and Marquis's (1969) cross-section of 567 innovations from 120 firms in five industries to analyze the nature of innovation by industry stage. They classified each firm into one of three stages, roughly equivalent to the three industry stages we delineated above, and found that product innovation counts started high and decreased, while process innovation counts started low and increased. Abernathy (1978) found a similar pattern in his in-depth study of the automobile industry. In addition, Abernathy, Clark, and Kantrow (1983) categorized 631 automobile innovations from 1893 to 1981 as product or process innovations, and Klepper (1997) analyzed time trends in these data. This analysis showed that although initially process innovations increased and product innovations decreased, the trend was eventually reversed as the industry experienced new upheaval owing to internationalization and shifts in demand. The importance of demand in driving patterns of innovative activity is also highlighted through simulation by Adner and Levinthal, (2001), who show that demand heterogeneity can explain the transition from product to process innovation in an industry.

One significant exception to this finding is McGahan and Silverman's (2001) study of patenting patterns across a broad range of industries from 1981–1997. Defining industries at the SIC code level, they found that even in the subset of technologically-oriented industries, patents did not reflect a shift from product to process innovation as industries matured (McGahan and Silverman, 2001).

Emergence of a dominant design. A key turning point in the evolution of many industries is the emergence of a dominant design, a generally accepted product architecture with standardized modules and interfaces, which incorporates a particular set of features. A dominant design codifies corresponding movements down two hierarchies, the design and need hierarchies, as technological choices are matched with articulations of preferences (Clark, 1985). Empirical work has identified dominant designs in a range of industries. Utterback and Suarez (Utterback and Suarez, 1993; Suarez and Utterback, 1995) identified dominant designs in the automobile, transistor, typewriter, TV picture tube, TV, and electronic calculator industries. They did not identify a dominant design in the supercomputer industry but postulated that one would emerge soon. Utterback and Suarez used interviews with industry experts to identify retrospectively the occurrence of a dominant design and the introduction date of the first product that incorporated those design parameters. Anderson and Tushman (1990) defined dominant design emergence as having occurred once a particular technology controlled over 50 % of a market. Using data from the cement, minicomputers, and glass industries, they found that in 12 of 14 cases where they hypothesized a dominant design should emerge, one did, and in the two exceptions, new technological discontinuities disrupted the industry before a dominant design had a chance to take hold. Other studies have identified dominant designs in the cochlear implant (Van de Ven and Garud, 1993), typesetter (Tripsas, 1997a), flight simulation (Rosenkopf and Tushman, 1998), synthetic dye (Murmann, 2003), and personal computer (Teagarden, Echols, and Hatfield, 2000; Bayus and Agarwal, 2007) industries.

Once a particular design emerges as dominant, firms focus their attention on improving and extending it. Periods of incremental technological change following the emergence of dominant designs have been documented in the cement, minicomputer, and glass (Anderson and Tushman, 1990), synthetic dye (Murmann, 2003), and machine tool (Noble, 1984) industries, among others. Stuart and Podolny (1996) used patent data to track technological distance, measuring a firm's technological niche as the extent to which the firm's patents built upon the same technology as other firms. Using data from the semiconductor industry from 1978 to 1992, they showed that, with the exception of one firm, the technological niche changed very little over that time period.

The progress made through these incremental improvements, however, can be significant. In the typesetter industry, once the hot metal linecaster architecture emerged as dominant around 1911, incremental innovations over a 50-year period resulted in hundredfold increases in speed (Tripsas, 2008). While a dominant architecture prevails, significant innovation can also occur in modular subsystems. New product generations in the mainframe computer, personal computer, and automobile industries incorporated improvements to subsystems that had major impacts on performance (Abernathy and Clark, 1985; Baldwin and Clark, 2000; Iansiti and Khanna, 1995; Bayus and Agarwal, 2007).

Emergence of a dominant design also accelerates diffusion of a technology across the heterogeneous set of potential adopters. An extensive marketing literature on the diffusion of innovations (e.g., Bass, 1969; Rogers, 1995) documented an S-shaped diffusion curve for most products and identified different segments of adopters over the lives of industries. Early adopters were willing to experiment and were often technically sophisticated users. Later adopters, however, preferred the comfort of a dominant design with clearly specified features and evaluation metrics.

Subsequent technological discontinuities. Much of the technology management literature has focused on technological discontinuities that disrupt the mature stage of an industry, creating a new period of turbulence akin to the first stage of the industry life cycle. These multiple cycles of discontinuous and incremental change are well documented. In the photography industry, collodion plates, gelatin plates, and roll film all sparked significant technological turmoil (Jenkins, 1975). Similarly, Cooper and Schendel (1976) document technological disruptions in many established industries, including conflicts between diesel locomotives (versus steam), ball point pens (versus fountain pens), nuclear power plants (versus fossil fuel plants), electric razors (versus safety blades), and jet engines (versus propellers). This type of discontinuous technological change has been shown to result in high levels of new entry into an industry after a period of relative stability as documented in the photolithography (Henderson, 1993) and typesetter (Tripsas, 1997b) industries.

Number of firms, entry, and exit. Although the technology life cycle literature defines stages by shifts in technology, and not shifts in numbers of firms, many studies have documented how the number of firms in an industry and entry/exit patterns relate to changes in technology. The basic pattern is highly consistent: early on there are high levels of entry with little exit, and later there is a shakeout, with high levels of exit and relatively little entry; the result is an inverted U-shaped pattern of the number of firms in an industry over time. As noted above, this pattern has been documented in the automobile, transistor, typewriter, TV tube, TV, electronic calculator, and supercomputer industries, with the shakeout coinciding with the introduction of the technology that eventually became the dominant design (Utterback and Suarez, 1993).

Empirical regularities in the technology management literature: firm performance

Much empirical work in the technology management tradition has focused on understanding the competitive implications of technological discontinuities – that is, what firms introduce new technologies, what characterizes firms that succeed technologically and commercially, and what firms are more likely to survive? (see Table 1.3 for a summary).

Where do technological discontinuities originate? Most studies show that new entrants – either start-ups or diversifiers – introduce radically new technologies into industries. In four of the seven industries Cooper and Schendel (1976) studied, the first commercial introduction of a product with radically new technology came from outside the industries. Tushman and Anderson (1986) classified innovations by how they affect the competencies of incumbent firms and showed that competence-enhancing discontinuities were more likely to originate with incumbent firms, and competence-destroying discontinuities, with new entrants.

TABLE 1.3 Technology management: empirical regularities in firm performance.

Key studies	*Sample and methods*	*Who develops the new technology?*	*Technical and commercial performance in the new technology*	*Survival*
Cooper and Schendel (1976)	Cross-section of industries: steam locomotives to safety razors and covering much of the 1800s and 1900s	New entrants were first in 4 of 7 industries		n/a
Henderson and Clark (1990) Henderson (1993)	Photolithography industry 1962–1986	New entrants	Incumbents underperform new entrants technologically and commercially in architectural innovations	n/a
Utterback and Suarez (1993)	8 industries: typewriters, TV, electronic calculators spanning 1874–1990	n/a	n/a	Pre-dominant design entrants have an increased likelihood of survival
Christensen and Bower (1996) Christensen, Suarez, and Utterback (1998)	Disk drives 1975–1990	Both incumbents and new entrants	Incumbents initially match new entrants technologically, but withdraw investment, and so underperform commercially	Entrants in a brief pre-dominant design window have a higher likelihood of survival

Mitchell (1989, 1991)	Medical Diagnostic imaging 1952–1989	Incumbents with specialized assets are more likely to enter	Incumbents with specialized assets that retain value perform well	Incumbents with specialized assets that retain value are more likely to survive
Tripsas (1997b)	Typesetter industry 1886–1990	Both incumbents and new entrants	Incumbents underperform new entrants technologically, but outperform them commercially due to possession of specialized complementary assets	n/a
King and Tucci (2002)	Disk drives	Both incumbents and new entrants	Incumbents with more experience in a prior generation are more likely to enter the new generation	n/a
Benner and Tushman (2003)	Paint and photography industries 1980–1999	n/a	Incumbents that invest heavily in process innovation (ISO 9000) underperform those that don't	n/a

(*continued overleaf*)

TABLE 1.3 (*continued*)

Key studies	*Sample and methods*	*Who develops the new technology?*	*Technical and commercial performance in the new technology*	*Survival*
Rothaermel and Hill (2005)	The computer industry, the steel industry, and the pharmaceutical industry 1972–1997	Both incumbents and new entrants	A competence destroying technological discontinuity decreases incumbent firm performance if the complementary assets of the new technology are generic, but increases it if they are specialized	n/a
Bayus and Agarwal (2007)	PC Industry, 1974–1994	Both incumbents (diversifying firms) and new entrants	Diversifying entrants are better able to migrate to the dominant design relative to entrepreneurial startups. However, entrepreneurial startups are more likely to introduce products with the latest technology	Diversifying entrants that enter early have a survival advantage over start-ups that enter early, but the reverse is true for late entrants

In some cases, what appears to be a technological discontinuity in a particular industry is actually the application of an incrementally developing technology from a different market. For instance, Levinthal (1998) traced the development of wireless communication as it sequentially revolutionized multiple new application domains and Tripsas (2008) extended this work, examining what sparked the movement of new technology between industries. She showed that major shifts in user preferences – preference discontinuities – could precipitate technological discontinuities as firms in an industry imported what was for them radically new technology from another industry.

Which firms succeed? Many studies have compared incumbents and new entrants and examined how the type of technological discontinuity influences which type of firm performs well, without distinguishing firm-specific strategies or behaviors. These studies have shown that for most types of technological discontinuities, incumbents underperform new entrants. This pattern was found when the new technology was competence destroying (Tushman and Anderson, 1986), architectural (Henderson and Clark, 1990), disruptive (Christensen and Bower, 1996), or destructive to the value of complementary assets (Tripsas, 1997b).

Several scholars have also examined the main and moderating effect of entry timing vis-à-vis the establishment of a dominant design in an industry (Suarez and Utterback, 1995; Christensen *et al.* 1998; Bayus and Agarwal, 2007). Suarez and Utterback (1995) and Christensen *et al.* (1998) examined how entry timing, as it related to the introduction of a dominant design, affected survival chances. Both studies defined the date of a dominant design as the year in which the first product with a design that eventually became dominant was introduced. Suarez and Utterback (1995) found that firms entering before a dominant design had a greater chance of survival than those entering after the dominant design. This effect was stronger the more distant a firm was from the date of the dominant design. In other words, firms that entered long after a dominant design was introduced were much worse off than those that entered immediately afterwards. Christensen *et al.* (1998), who used data from the disk drive industry, found that firms were still better off entering before the dominant design date, but the benefit was limited to a short window of three years beforehand. Bayus and Agarwal (2007) found evidence consistent with these studies on the main effect of entering before or after the dominant design, and additionally examined how entry timing, product technology strategy, and entrant capabilities may interact to explain performance differentials. They found that the survival advantage of diversifying entrants over entrepreneurial startups in the pre-dominant design stage is reversed in the post-dominant design stage. They explained this result by demonstrating that the product technology strategies related to higher survival rates differed by entry time and pre-entry experience.

Finally, there is extensive literature examining how specific firm-level change mechanisms, including shifts in organizational structure, external relationships, and investments in innovative activity affect firm performance. Reviewing this literature in depth is beyond the scope of this paper; however, we have highlighted significant mechanisms. First, organizational structure appears to play a significant role, with completely separate organizations (Gilbert, 2005) and ambidextrous organizations (O'Reilly and Tushman, 2008) achieving superior results when simultaneously managing old and new technologies. Second, external knowledge transfer from acquisitions (Ahuja and Katila, 2001), formal alliances (Rothaermel, 2001), and informal infrastructures (Tripsas, 1997a) is beneficial in transforming the organization's knowledge base. Finally, managing the tension between investments in exploitation and exploration is also critical (Katila, 2002; Taylor and Greve, 2006), with excess investment in activities such as Total Quality Management (TQM) limiting a firm's ability to explore (Benner and Tushman, 2002).

Empirical regularities in the evolutionary economics literature

Research in evolutionary economics has linked systematic changes in the technological characteristics and sources of innovations to the various stages in the evolution of an industry. In Table 1.4, we provide the main empirical findings of key studies in evolutionary economics, and below we summarize the robust patterns that can be seen in that research for number of firms, entry and exit rates, output, price, and firm performance.

Number of firms, entry, and exit. Perhaps the most robust empirical regularity documented in the evolutionary economics literature is the pattern exhibited in the numbers of firms in industries over time. Starting with Gort and Klepper (1982), evolutionary economists have studied multiple industries by using panel data that allow them to track the time trends in number of firms, entry, and exit. Gort and Klepper (1982), in a study of the diffusion of 45 product innovations, identified five distinct industry life cycle stages (see Figure 1.2). Klepper and Graddy (1990) grouped some of these stages to highlight growth, shakeout, and maturity. In particular, these studies show that 83 % of the industries in their samples conform to the stylized patterns for number of firms depicted in Figure 1.2. Tracking the (relatively young) industries that did not conform to the pattern, Agarwal (1998) extended the time series and found that the numbers of firms in several of these industries also conformed to the stylized pattern.[2] Particularly noteworthy in these studies was the severity of the shakeouts and the subsequent stability in number of firms; on average, the industries exhibited a 40 % decline in number of firms from their peaks, with several industries experiencing a more than 70 % decline. Furthermore, the industry life cycle may be contracting over chronological time; preliminary evidence provided in Gort and Klepper (1982) and systematic investigation of the issue by Agarwal and Gort (2001) revealed that the time until competitive entry into an industry occurs has decreased. For instance, it took 33 years for competitive entry to occur in the phonograph industry in the early 20th century, and only three years for the same to occur in the CD player industry in the late 20th century.

Klepper and Miller (1995) and Agarwal and Gort (1996) examined the gross entry and exit trends that underlay trends in number of firms and found that

[2]Rather than using stages in the life cycle, Agarwal (1998) regressed number of firms on industry age for 33 industries and found a quadratic functional form to be the best fit for the data for 26 of these industries.

TABLE 1.4 Evolutionary economics: empirical regularities in industry patterns.

Key studies	*Sample*	*Number of firms, entry and exit*	*Innovative/technological activity*	*Output, sales, and market share*	*Prices*
Gort and Klepper (1982)	46 industries spanning 1887–1960	An inverted U-shaped curve for the number of firms over the industry life cycle – decomposed into five stages	Major innovations occur early, and minor innovations occur later in the industry life cycle. Increase rate of patenting activity over the five stages of the life cycle	Output increases over the life cycle, but the rate in growth of output steadily declines over the consecutive stages	Greatest percentage decreases in the early stages of development, with a decreasing rate of decline thereafter
Klepper and Graddy (1990)	46 industries 1887–1960	The inverted U-shaped curve for number of firms is used to characterize the three stages in the life cycle: growth, shakeout, and mature stage	Major innovations, particularly from small entrants and entrants from related fields occur early in the life cycle. Later innovations are incremental in nature	The average percentage change in output is greatest in the first five-year interval, and subsequently declines over the next five five-year intervals	The annual percentage decline in price is greatest in the first five-year interval, and monotonically declines in absolute value over all the next five-year intervals

(*continued overleaf*)

TABLE 1.4 (*continued*)

Key studies	*Sample*	*Number of firms, entry and exit*	*Innovative/technological activity*	*Output, sales, and market share*	*Prices*
Lieberman (1990)	30 chemical industries spanning 1961–1987	There was a 32 % decline in the number of firms in the sample of declining industries		Output in the sample of declining industries decreased by an average of 42 %	
Jovanovic and Mac-Donald (1994a,b)	Automobile tire industry 1906–1973; diesel locomotive engines 1925–1966; semiconductor industry 1978–1986	An inverted U-shape in number of firms	Innovation opportunities fuel entry, and relative failure to innovate results in exit. Diffusion of technology over time due to spillovers of technology and increased imitation effort by 'laggard' firms	Output increases, but at a decreasing rate. Stock market share prices indicate rising value in the growth period of automobile tires, and drops in value during the shakeout period	Price declines exponentially in the initial years of the industry

Audretsch (1995)	Small Business Database (almost every manufacturing firm) from 1976–1986	Entry rates are higher in periods of high ratios of small firm innovation to total innovation	There are systematic differences over time in small firm innovation rates; the entrepreneurial regime is characterized by a higher level of small firm innovation relative to the total innovation rate		
Agarwal and Gort (1996)	25 industries spanning 1908–1991	An inverted U shaped curve in the number of firms; gross entry rates peak early in Stage 2, while gross exit rates peak early in Stage 4 (see Figure 1.1)			
Agarwal (1998)	33 industries spanning 1908–1991	The number of firms in the industry has a quadratic relation to industry age	The number of patents has a quadratic relation (inverted U shape) to industry age, with the peak in patenting activity occurring after the peak in the number of firms	Output increases at a decreasing rate over industry age	Price declines at a decreasing rate over industry age

(*continued overleaf*)

TABLE 1.4 (*continued*)

Key studies	*Sample*	*Number of firms, entry and exit*	*Innovative/technological activity*	*Output, sales, and market share*	*Prices*
Klepper and Simons (2000a)	Television receiver industry 1947–1989	A confirmation of the above empirical regularities; diversifying entrants from related industries enter earlier than other types of entrants	Diversifying entrants from radio (a related industry) had higher product and process innovation rates than other entrants	Output increases at a decreasing rate over industry age	Price declines at a decreasing rate over industry age
Filson (2001)	Automobiles, personal computers, rigid disk drives, computer monitors, and computer printers	An inverted U-shaped pattern in the number of firms	No evidence in support of the notion that new industries experience quality innovation early on and cost innovation later on. In the microelectronics industries the rate of quality improvement does not diminish over time. In the automobile industry, even though the rate of quality improvement is highest early on, the profitability of quality advantages is highest later on	Output increases at a decreasing rate over industry age	Price declines are most rapid early in the industry's history, and slow down later in the life cycle

Agarwal and Bayus (2002)	30 industries spanning 1849–1991.	Early period of the industry is characterized by a hockey stick pattern in the number of firms – a sharp takeoff in number of firms characterizes the onset of the growth stage		Early period of the industry is characterized by a hockey stick pattern in the industry output – but the sharp takeoff in output is preceded by the takeoff in the number of firms	Prices are generally declining in the early period of the industry
Klepper and Simons (2000a)	Automobiles 1895–1966; Automobile tires 1905–1981; Televisions 1946–1989; Penicillin 1943–1992.	Number of firms follows an inverted U shaped pattern. Initially, a surge in entrants causes the number of firms to rise dramatically. Entry then slows markedly and coupled with relatively steady exit rates causes a severe shakeout of firms		All four industries became oligopolies with several firms commanding much of the market; output continued to grow after the shakeout	

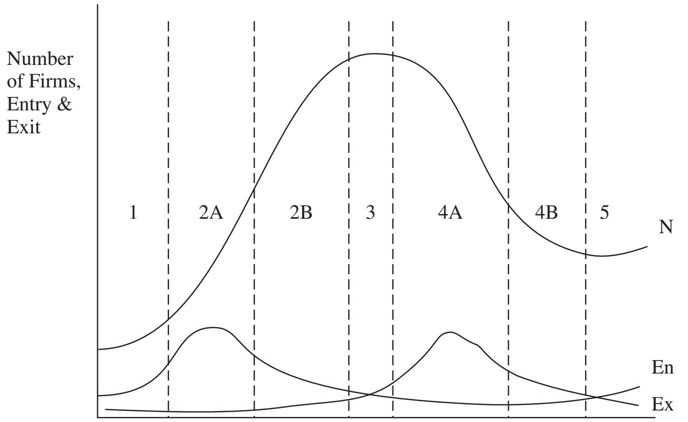

FIGURE 1.2 Entry, exit, and number of firms across stages.

the trend in gross entry peaked early in the growth stage while the trend in gross exit peaked in shakeout stage 4 (see Table 1.5). Several studies replicated these findings for other industries, depicting the robustness of these patterns across consumer/industrial and technologically intensive and nonintensive industries alike (Lieberman, 1990; Audretsch, 1995; Klepper and Simons, 2000b; Filson, 2001; Agarwal and Bayus, 2002).

Innovative and technological activity. Many of the evolutionary economics studies identify innovation and technological change as a key driver for industry evolution, and as a result, several scholars have examined technological activity for distinctive empirical regularities. Gort and Klepper (1982) examined the timing of major and minor innovations, and found that major innovations were typically introduced early in the industry life cycle. Jovanovic and Macdonald (1994a, b) modeled innovative activity as the causal driver of the patterns observed for key industry variables over the life cycle. In Jovanovic and MacDonald (1994a) for instance, the competitive diffusion was a result of innovation by the technological leaders, and imitation activity by the laggards in the firm. In Jovanovic and MacDonald (1994b), entry was initially fueled by innovative opportunities and shakeout occurred due to failure of firms to innovate in the later stages. Audretsch (1995) identified systematic differences over time between the innovation rate in small manufacturing firms and the total innovation rate, which he interpreted as indicative of the growth stages or 'entrepreneurial regimes' in manufacturing industries. Thus, in keeping with the technology studies discussed above, evolutionary economists identify the bulk of the innovations introduced later in the industry life cycle as minor or incremental.

Although patenting activity may not capture all innovation, Agarwal (1998) examined patent trends across 33 industries and found that the number of patents increased initially, but then fell over time. This effect was most profound in the

TABLE 1.5 Standardized annual entry, exit, and number of firms by stages for 25 product markets.*

	Stage						
	1	*2A*	*2B*	*3*	*4A*	*4B*	*5 (to 1991)*
Number of years							
Mean	9.76	13.68	5.77	6.38	10.05	7.06	15.00
Median	7.00	10.00	3.50	5.00	9.00	7.00	10.00
Average entry							
Mean	0.59	1.77	1.50	0.91	0.51	0.53	1.03
Median	0.44	1.50	1.33	0.90	0.47	0.51	0.93
Average exit							
Mean	0.15	0.58	0.94	1.45	2.06	1.10	0.99
Median	0.02	0.46	0.81	1.35	2.03	0.99	0.92
Average number of firms							
Mean	0.20	0.95	1.39	1.58	1.24	0.91	1.07
Median	0.41	0.87	1.37	1.51	1.22	0.89	1.08

*All statistics except number of years were standardized by taking the ratio for each product of the average value of the relevant statistic (entry, exit and number of firms) per year in each stage to its average value per year across all stages experienced by the product.

Source: Reproduced from Agarwal and Gort (1996)

high-technology context, where 75 % of industries exhibited this pattern, as opposed to 55 % in other settings. Interestingly, a comparison of the peaks in patents and in numbers of firms revealed that, particularly for technologically intensive industries, the peak in patenting activity occurred after the peak in the number of firms.

Although evolutionary economists have not studied the rates of product versus process innovation in depth, a few studies address whether there are systematic differences in the rates of product and process innovation in the industry life cycle. Klepper and Simons (1997) examined the automobile industry and found that product innovation owing to commercialization had peaked by the first decade of the 20th century, whereas process innovation was very low during this period. The rate of process innovation increased subsequently, with the most dramatic improvements in manufacturing occurring when Ford pioneered the moving assembly line (1913–14). However, Filson (2001) found evidence to the contrary; in his examination of five technologically intensive industries, he obtained no support for the notion that new industries experience product innovation early on and cost (process) innovation later in the life cycle. In particular, his study showed that the rate of quality improvements did not, in general, diminish over time. In addition, even in the automobile industry, where there was evidence of product innovations being highest early on, Filson (2001) found that the profitability of quality advantages was greatest during the later stages.

Furthermore, Klepper and Simons (2000a) examined the source of the innovative activity and found that firms with pre-entry capabilities had superior technological and experiential resources. Examining entry into the television receiver industry, they found that radio producers had higher product and process innovation rates than did other entrants, and their early entry into the industry had a significant impact on the industry evolution.

Industry output, sales, and market share. Evolutionary economics studies also demonstrate a consistent pattern in industry output or sales. Gort and Klepper (1982) and later researchers documented systematic increases in industry sales followed by steady decline in the growth of output (Klepper and Graddy, 1990; Jovanovic and MacDonald, 1994a, b; Klepper, 1997; Agarwal 1998; Filson, 2001; Agarwal and Bayus, 2002). Together, these studies examined over 50 industries to find remarkable consistency across these markets.

The evolutionary economics studies are also corroborated by marketing research investigating the evolution in the sales of successful consumer and industrial product innovations (e.g., Mahajan, Muller, and Bass, 1990; Moore, 1991; Rogers, 1995; Golder and Tellis, 1997). In most new industries, there is evidence of a 'takeoff' point, the first distinct, large increase in sales. The time between industry inception and sales takeoff varies significantly across industries; some products achieve sales takeoff within five years of their commercial introduction, but others have low sales for more than 20 years after their inception (Mahajan, Muller, and Bass, 1990; Golder and Tellis, 1997; Agarwal and Bayus, 2002).

An interesting question arises about the interplay of number of firms and sales takeoff. Examining the emergence stages of 30 new industries more closely, Agarwal and Bayus (2002) found a distinct hockey-stick pattern in the time trend for both number of firms and sales, highlighting a discontinuous takeoff point in each of these industry variables. Furthermore, they found that the takeoff in the number of firms ('firm takeoff') systematically preceded the takeoff in sales. Although there was significant variation across industries, the average time between commercialization and firm takeoff was six years, and the time between firm and sales takeoff was eight years. Approximately 13 % of all potential competitors entered before firm takeoff and, interestingly, another 30 % of all potential competitors entered in the period between firm and sales takeoff. Thus, by the time that significant sales occurred, almost 44 % of all potential competitors had already entered the market.

At the other end, Lieberman (1990) examined the decline of 30 chemical industries and found that their output decreased by an average of 42 %. His study also provides evidence of the interplay between firms and output. He found evidence for both 'stake-out' and shakeout in this sample: the decline in output was systematically related to small firm exits, and also to plant closures and decreases in capacity for the larger firms in the sample.

Prices. Studies examining price trends in evolutionary economics once again show remarkable consistency. Gort and Klepper (1982) and Klepper and Graddy (1990) documented that the average annual percentage decline in price was highest in the first five years of an industry and then declined steadily over subsequent five-year intervals or stages in the life cycle. Other studies corroborate the finding that prices decline, but at a declining rate (Jovanovic and MacDonald, 1994a, b; Agarwal, 1998;

Klepper and Simons, 2000b; Agarwal and Bayus, 2002; Filson, 2001). Once again, marketing studies support these findings, showing an exponential time trend ($\lambda e^{\theta t}$) to be the best fit for the trend in prices observed in industry life cycles (Bayus, 1992; Bass, 1995).

The overall declining trend in prices is observed in almost all industries, yet there is nonetheless considerable variation in the rate of decline, with some industries taking longer to exhibit price declines than others. Agarwal and Bayus (2002) found the declines in price trends to be systematically correlated with the technology intensiveness of the industries; in markets that exhibited high R&D costs, the price declines were much smaller than in industries with lower R&D costs.

Firm performance. The last ten years have seen an increasing focus on the determinants of firm survival in the context of industry life cycles, in addition to other measures of firm performance. Although several of the evolutionary economics studies emphasize environmental selection mechanisms, recent research has also begun to examine empirical regularities related to firm-specific characteristics. Table 1.6 highlights some of the key findings related to firm performance.

Research on evolutionary economics is related to the literature on first mover advantages and order of entry, but its focus is more on systematic variations in firms' performance that arise from the life cycle stage at which firms enter an industry. Almost all the empirical studies show that entering early in the industry life cycle bestows survival advantages (Agarwal and Gort, 1996; Klepper and Simons, 2000a; Agarwal, Sarkar, and Echambadi, 2002; Klepper 2002b). In addition, studies have also examined how the timing of entry and life cycle stage may condition important relationships between firm and industry characteristics and firm performance. We turn to these aspects below.

The relationship between firm survival and age has been documented with the use of hazard rate analysis. Some evolutionary studies confirm that hazard rates decline monotonically with age (Klepper and Simons, 2000a; Klepper, 2002a,b) in a manner similar to other studies based on longitudinal, but not industry evolution data (see the review by Sutton, 1997). However, other studies indicate that the industry life cycle may affect this relationship. Agarwal and Gort (1996) found that the hazard rates of early entrants exhibit nonmonotonicity – the hazard rates of early-stage entrants exhibited an initial increase, a period of decline, and a subsequent increase, which the authors attributed to 'senility'. In contrast, later-stage entrants exhibited the highest hazard rates immediately after entry, and their hazard rates declined as they aged, though these rates also began to increase after a certain point.

Similarly, in studying the relationship between firm performance and firm size in the context of industry evolution, researchers find broad support for the positive relationship between firm size and survival or market share, a relationship captured in our initial description of industry development (Klepper and Simons, 2000b; Agarwal, Sarkar, and Echambadi, 2002; Sarkar *et al.,* 2006; Bayus and Agarwal, 2007). However, disadvantages related to size may differ over the course of the industry life cycle, and based on the technological intensity of the industry. Lieberman (1990), focusing on the declining stage only, found that small firms

TABLE 1.6 Evolutionary economics: empirical regularities in drivers of firm performance.

Key studies	*Sample*	*Timing of entry*	*Age of firm*	*Size of firm*	*Pre-entry experience*	*Technology and other variables*
Lieberman (1990)	30 chemical industries spanning 1961–1987			In industries facing decline, small firms exited at a disproportionately higher rate than large firms		In industries facing decline, single product firms are less likely to exit the market than diversified firms
Audretsch (1991)	11 000 firms in 295 4-digit SIC industries.					Survival is promoted by small-firm innovative activity, but is lower in industries with economies of scale, and high capital-labor ratio

Agarwal and Gort (1996)	25 industries spanning 1908–1991	Entrants in earlier stages have higher survival rates relative to entrants in later stages	Hazard rates of early entrants have an inverted-U shaped relationship with firm age, while hazard rates of late entrants generally decrease monotonically with age			High technology intensity industries have higher ratios of entrant to incumbent survival rates
Klepper and Simons (2000a)	Television receiver industry 1947–1989	Pre-entry experi-enced firms enter earlier than other firms, and survival is positively related to timing of entry		Larger diversifying entrants (radio producers) entered earlier, and had higher survival rates and market shares relative to all other types of firms	Diversifying entrants (radio producers) survived longer and had larger market shares relative to other entrants	Firm level innovation is positively related to survival rates

(*continued overleaf*)

TABLE 1.6 (*continued*)

Key studies	*Sample*	*Timing of entry*	*Age of firm*	*Size of firm*	*Pre-entry experience*	*Technology and other variables*
Klepper (2002a,b); Klepper and Simons (2005)	Automobiles 1895–1966; Automobile tires 1905–1981; Televisions 1946–1989; Penicillin 1943–1992	Early entrants have higher survival rates than late entrants. Early entrants are by far the dominant source of innovation	Hazard rates decline with age of the firm		Inexperienced firms have a higher hazard than experienced firms at all ages and in all entry cohorts.	Higher rates of innovation caused the longer survival of early entrants and affected the survival of all market entrants.
Agarwal, Sarkar, and Echambadi (2002)	33 industries spanning 1908–1991	Entrants in the growth phase have higher survival rates than entrants in the mature phase	Liability of newness is observed for firms entering in the mature phase, but not in the growth phase	Liability of smallness is higher in the growth phase relative to the mature phase		There is a U-shaped relationship between failure rates and density for firms existing in the growth phase, or for firms that enter in the mature phase, but no relationship between density and mortality for growth entrants that transition to mature phase

Agarwal and Bayus (2004)	22 industries spanning 1887–1991	Controlling for industry age effects, early entry cohorts have higher survival rates, but do not have higher market share or percentage of new model offerings	The probability of survival *decreases* with firm age	Size of the firm is positively related to both survival rates and the percentage of new model offerings	The interaction of pre-entry experience and industry age is negative; the advantages of pre-entry experience in terms of survival and market share dissipate (and even reverse) over time	New model offerings by entrepreneurial start-ups increase over the industry life cycle
Cefis and Marsili (2005)	Broad cross-sectional survey of businesses in the Netherlands 1996–2003		Older firms are less likely to fail	Larger firms are less likely to fail		Firms that have higher rates of process innovation are more likely to survive. Effect is most pronounced in high technology sector

(*continued overleaf*)

TABLE 1.6 (*continued*)

Key studies	*Sample*	*Timing of entry*	*Age of firm*	*Size of firm*	*Pre-entry experience*	*Technology and other variables*
Sarkar, Echambadi, Agarwal, and Sen (2006)	33 industries spanning 1908–1991	Firms that enter in the growth stage (entrepreneurial regime) have higher survival probabilities relative to firms that enter in the mature stage (routinized regime)		Liability of smallness is observed only in the 'non-aligned' innovative environments		The innovative environment (two-dimensional measure based on industry life cycle and technological intensity) increases survival rate, and disproportionately benefits small firms relative to large firms

are disproportionately more likely to exit than large firms; however, a comparison of survival rates over life cycle stages indicates that the liability of smallness may be higher in the growth phase than in the mature phase (Agarwal, Sarkar, and Echambadi, 2002). A recent study by Sarkar *et al.* (2006) found that aligned innovative environments – defined two dimensionally as the growth stage of technologically intensive industries – mitigated the liability that small firms experienced in partially aligned or nonaligned environments that arose in mature stages, low technology industries, or both.

Heterogeneity in pre-entry and subsequent capabilities is another important factor examined in evolutionary economics studies. Although we present a brief synopsis of the main findings here, we refer interested readers to the in-depth review by Helfat and Lieberman (2002), and the identification of stylized facts in Bayus and Agarwal (2007). Researchers have distinguished between entrepreneurial start-ups and diversifying firms from related industries (Klepper and Simons, 2000a; Klepper, 2002a; Bayus and Agarwal, 2007). Klepper and Simons (2000a) showed that radio producers tended to enter the television receiver industry earlier than other entrants and also experienced higher market shares and survival rates. Furthermore, these diversifying entrants had higher rates of innovation, and they dominated over the other firms for much of the industry life cycle.

Pre-entry experience also matters at the more micro level of analysis. Klepper (2002a) and Agarwal *et al.* (2004) further identified the distinct class of entrepreneurial start-ups whose founders had pre-entry experience in a focal industry and found that such spinouts had lower failure rates relative to every other type of entrant. There is. however, some evidence that the industry life cycle may condition the pre-entry experience–firm performance relationship. Bayus and Agarwal (2007) showed that the performance advantages of diversifying entrants, which accrued due to differences in product technology strategies, dissipated over time.

Finally, industry-level characteristics such as technological intensity have also been shown to affect firm performance. Corroborating findings about firm-level innovation and technology strategy (Klepper and Simons, 2000a; Bayus and Agarwal, 2007), scholars have shown that at the industry level too, technological intensity can have a positive effect on overall survival rates, particularly for entrants (Agarwal and Gort, 1996; Sarkar *et al.* 2006).

Empirical regularities in the organization ecology literature

Organizational ecologists have sought to explain how social environments shape the evolution of industries, in particular changes in organizational populations over time. Although technological change has not been the explicit focus of research in this tradition, many of the patterns studied in this literature inform our understanding of technology and industry evolution. Two aspects are particularly relevant – the determinants of the number of organizations/entry rates in an industry over time, and the determinants of organizational survival. For our purposes we focus on ecological studies set in technology-based industries (see Singh and Lumsden (1990) and Baum and Amburgey (2002) for more comprehensive reviews).

Number of organizations (population density) and entry (founding). Empirical studies in organizational ecology have traced the number of organizations in an industry from its inception through maturity, documenting the same highly robust pattern found in the technology management and evolutionary economics literature: the number of organizations (population density) starts low, increases rapidly, peaks, and then begins to decline (see Table 1.7). This pattern was initially documented in a range of settings including American labor unions (Hannan and Freeman 1987, 1988) newspapers (Carroll and Delacroix, 1982), and microbreweries (Carroll and Swaminathan, 2000), but it has also been documented in technology-based industries including telephones (Barnett, 1990), fax machines (Baum, Korn, and Kotha, 1995), disk arrays (McKendrick and Carroll, 2001) and microprocessors (Wade, 1995).

In addition to noting patterns in the overall number of organizations, organizational ecologists have focused on the drivers of gross entry into an industry. The dominant finding – density dependence – is an inverted U-shaped relationship between entry rates and population density. Increases in the population of organizations initially drives increased levels of entry due to legitimization, but eventually competition associated with high levels of density discourages entry. This pattern also holds for technology-based industries. Wade (1995, 1996) studied entry patterns in the microprocessor industry. Instead of looking at aggregate industry density, he split the industry into technical communities, each comprised of a leading firm that sponsored one or more designs, and second source firms that followed. Wade found that sponsor entry had an inverted U relationship with the number of technical communities, and second source entry had an inverted U-shaped relationship with both the density of communities within the industry, and with the density of second source firms within each community.

Baum, Korn, and Kotha (1995) examined facsimile transmission service organizations in the context of the establishment of a dominant design. They documented the growth in the number of facsimile producers from the inception of the industry in the late 1960s through the 1980s, with the establishment of the dominant design occurring in 1980. Their findings for Manhattan area organizations showed an important interplay between the setting of the dominant design and ecological processes of entry and exit. Entry rates increased over time during the pre-dominant-design period but were suppressed immediately after the establishment of a dominant design. However, the effect of the dominant design on both entry and exit rates attenuated over time, disappearing altogether from four to six years after the dominant design standard was set.

Organizational mortality. In addition to relating founding rates to population density, a key area of interest in organization ecology relates to the determinants of organizational mortality. Table 1.8 lists key studies in technology-based industries that have examined the relationship between firm mortality and environmental and firm characteristics. A key empirical regularity in the organizational ecology literature relates to the mortality–density relationship. Researchers have consistently found that failures initially tend to decrease with increases in density, and then increase (e.g., Hannan and Freeman, 1988; Carroll and Hannan, 1989; Baum and Oliver 1991; Carroll *et al.*, 1996). An integrative study by Agarwal, Sarkar, and

TABLE 1.7 Organizational ecology studies: empirical regularities in industry patterns for technology-based industries.

Key studies	*Sample*	*Number of firms (density)*	*Entry (founding) rates as a function of density*
Baum, Korn, and Kotha (1995)	Facsimile transmission service organizations 1965–1992	Number of firms is relatively flat, and then increases dramatically once a dominant design emerges	Entry rates increased over time during the pre-dominant design period, were suppressed immediately after the setting of dominant design, but the suppression effect attenuated over time. Entry rates had an inverse U shaped relationship with the focal firm's cohort density
Barnett (1990)	Telephone companies in Pennsylvania 1877–1934 and telephone companies in Southeast Iowa 1900–1930	Number of firms first increases, and then decreases, although decrease is substantially more pronounced in Pennsylvania	There is a surge of firms entering in the first seven years after two Bell Telephone Companies' patents expired
Wade (1995)	Microprocessor industry 1971–1989	n/a	Second source entry has an inverted U shape relationship with density of communities and density within community
Wade (1996)	Microprocessor industry 1971–1989	During most of the time period, density of sponsor firms increases, but at a decreasing rate. There is a slight decrease in density at the very end of the time period	Sponsor entry has an inverted U shape relationship with density of communities. Sponsor entry has a negative relationship with the density of second source firms

TABLE 1.8 Empirical regularities in firm survival from organizational ecology studies.

Key studies	*Sample*	*Number of firms (density)*	*Age of firm*	*Size of firm*	*Pre-entry experience and other variables*
Freeman, Carroll, and Hannan (1983)	US semiconductors 1951–1979, local newspapers 1800–1975, and American National Labor Unions 1860–1980	n/a	Failure rates decrease monotonically with age, with the initial failure rate being almost five times higher than the asymptote rate	Size increases the likelihood of failure	n/a
Barnett (1990)	Telephone companies in Pennsylvania 1877–1934 and telephone companies in Southeast Iowa 1900–1930	Failure rates increase with density of firms using the same technology, but can actually decrease with density of firms using a different but complementary technology	In the Pennsylvania sample, failure rates increase with firm age; failure rates were not affected by firm age in the Iowa sample	Size of firm was not found to be significant	Failure rates decreased with market size

Baum, Korn, and Kotha (1995)	Facsimile transmission service organizations 1965–1992	Failure rates for pre-dominant design cohort firms increase with own cohort density Failure rates for post-dominant design cohort firms increase with pre-dominant design cohort density, but have a U-shaped relationship with own cohort density	Failure rates for pre-dominant design cohort firms increase with firm age; failure rates of post-dominant design cohort firms were not affected by firm age	Failure rates for the pre-dominant design cohort increase with analog sales but decrease with digital sales; reverse is true for the post-dominant design cohort	Diversified entrants had lower failure rates than firms offering only facsimile services; the establishment of the dominant design decreased (increased) failure rates of the pre-dominant design (post-dominant design) cohorts, but this effect attenuates over time; the failure rates for firms in the pre-dominant design cohorts decrease with number of firms founded and number of firms failed in the same cohort
Carroll, Bigelow, Seidel, and Tsai (1996)	US automobile industry 1885–1981	Failure rates have a U-shaped relationship with density	Failure rates decrease with firm age	Failure rates decrease with size	Entrepreneurial start-ups (*de novo* entrants) have higher failure rates than diversifying entrants (*de alio* entrants); this effect attenuates over firm age

(*continued overleaf*)

TABLE 1.8 (*continued*)

Key studies	*Sample*	*Number of firms (density)*	*Age of firm*	*Size of firm*	*Pre-entry experience and other variables*
Dobrev, Kim, and Carroll (2003)	US automobile industry 1885–1981	Failure rates increase with density of firms whose niche overlaps focal firms' niche	n/a	Larger firms are less likely to initiate a change. The risk of failure for a firm changing market niches has an inverted U shaped relationship with size	Failure rates have inverse relationship with tenure in industry. Experience with change makes a firm more likely to survive subsequent change
Dowell, and Swami-nathan (2006)	US bicycle manufac-turers (1880–1918)	Failure rates have a U-shaped relationship with density	Failure rates decrease with firm age	Failure rates decreases with firm size	Failure rates are lower for firms that entered the industry earlier, but the effect only lasts until the establishment of a dominant design. After the establishment of the dominant design, failure rates are higher for firms that were founded with technology that is distant from dominant design. Failure rates are higher for firms that enter with the dominant design

Echambadi (2002) showed that the stage of industry life cycle conditions the density-mortality relationship. They found evidence for a U-shaped relationship between failure rates and number of firms in an industry's growth stage and for firms that enter in its mature stage, but they found no relationship between competitive density and mortality for growth-stage entrants that transitioned into the mature phase.

Among firm-specific characteristics, organizational ecologists have studied the effects of age and size on firm survival. Although early organizational ecology studies (e.g., Carroll and Delacroix, 1982; Freeman, Carroll, and Hannan, 1983) generally found evidence for a 'liability of newness', i.e., young organizations are more likely to die than older organizations, more recent studies have documented both 'liability of adolescence' (Bruderl and Schussler, 1990; Fichman and Levinthal, 1991) and 'liability of senescence' (Barron, West, and Hannan, 1994; Khessina, 2003). Similarly, studies document a 'liability of smallness', a remarkably consistent finding that size is negatively related to firm failure (Freeman, Carroll, and Hannan, 1983; Hannan and Freeman, 1988; Baum and Oliver, 1991; Carroll *et al.*, 1996).

Although density, age, and size are relevant in technology-based industries, most studies also examined other firm characteristics. Carroll *et al.* (1996) found that diversifying entrants in the automobile industry, particularly from related industries, had a significantly lower failure rate than entrepreneurial start-ups.

In his 1990 study of telephone companies, Barnett split the industry along technological lines, between magneto and the more advanced common battery firms. He then also split the common battery firms into single exchange and multi-exchange firms and found that common battery firms only competed with common battery firms with the same type of exchange. In addition, increased density of multi-exchange firms actually decreased the failure rate of single exchange firms, and vice versa. Thus, Barnett (1990) argued that populations of firms with complementary technologies could have a mutual relationship. Finally, in her dissertation work, Khessina (2003) linked pre-entry experience with innovative behavior in the optical disk drive industry. She found that whereas startups innovated at a higher rate than diversifying entrants, the more developed competencies of diversifying entrants resulted in longer market life spans for their products.

Theoretical Perspectives

The earlier section highlights the impressive regularities in the evolutionary trajectories that have been observed in diverse product innovations and industries; however, it has been removed from the underlying theoretical perspectives with which the evolution of the industries have been examined. In this section, we compare and contrast the theoretical perspectives of the three main bodies of literature reviewed above: technology management, organizational ecology, and evolutionary economics, focusing on the complementary or contradictory explanations of key questions that the three streams offer (see Table 1.9).

Why is there a flurry of entry early on? Although all three of these research streams document high levels of entry early in an industry, the underlying drivers that

TABLE 1.9 Theoretical underpinnings of key stylized facts in the industry evolution literature.

	Why do we see 'herds' of entrants?	*What drives convergence on a dominant design*	*What drives the shakeout?*	*Who has a higher probability of survival and why*
Technology management	R&D is on a small scale enabling new entrants to compete effectively (Mueller and Tilton, 1969) Technical variety of entrants enables industry-wide experimentation (Utterback and Abernathy, 1975)	Interactions among institutional arrangements, resource endowments, and technical economic activities (Van de Ven and Garud, 1993; Tushman and Rosenkopf, 1992) Interactions among beliefs, artifacts, and routines (Garud and Rappa, 1994) Consensus building in community networks (Rosenkopf and Tushman, 1998) The interaction of firm-level and environmental factors (Suarez, 2004)	The dominant design enables standardization and investments in process innovation to increase minimum efficient scale (Abernathy and Utterback, 1978) Dominant design causes increase in competitive pressures resulting in exit of inefficient firms and mergers of small and specialized firms with the dominant firms (Utterback and Suarez, 1993)	Pre-dominant design entrants have a higher survival probability. These firms accumulate collateral assets, benefit from experimentation, and benefit from economies of scale and increasing barriers to entry/mobility (Suarez and Utterback, 1995)

Evolutionary economics	Differences in information conditions by life cycle stage (Gort and Klepper, 1982; Winter, 1984)	Decreased variety resulting from the shakeout causes convergence on a dominant design (Klepper, 1996)	Rise in innovation that increases barriers to entry (Gort and Klepper, 1982)	Emergence/growth stage entrants have a high survival probability. These firms are the source of innovation, and also benefit from a growth in demand (Agarwal and Gort, 1996)
		Increasing returns to scale due to network externalities result in tipping towards a single technology	Firm growth results in higher incentives for process innovation and economies of scale that drives shake-out (Klepper, 1996)	Diversifying entrants from related industries have a higher survival probability. These firms enter earlier, have the most relevant knowledge for the focal industry, and innovate at higher rates than other firms (Klepper and Simons, 2000a)
			Increasing adoption of external innovation that increases barriers to entry (Jovanovic and MacDonald, 1994a,b)	Stage of life cycle conditions the relationships of key firm/industry variables with survival. Structural changes in the competitive conditions cause and the intensification of survival barriers interact with firm heterogeneity to cause differential effects on survival (Agarwal, Sarkar, and Echambadi, 2002)

(*continued overleaf*)

TABLE 1.9 (*continued*)

	Why do we see 'herds' of entrants?	*What drives convergence on a dominant design*	*What drives the shakeout?*	*Who has a higher probability of survival and why*
Organization ecology	Increased social and political legitimacy that accompanies initial increases in density	Not addressed	Overcrowding. High contemporaneous density, causes competitive pressures to overshadow legitimization effects causing a negative effect on founding rates, along with an increase in exit (failure) rates (Hannan and Carroll, 1992; Hannan and Freeman, 1989 Founding density create *liability of resource scarcity* and force firms with inferior resources to exit (Carroll and Hannan, 1989)	Early entrants have a higher survival probability. Firms that enter in periods of resource munificence perform better than firms that enter in periods of resource scarcity (Hannan and Freeman, 1989; Hannan and Carroll, 1992) 'Specialist' firms in the initial period have a higher survival probability since they are better able to withstand environment fluctuations and uncertainty; 'generalist' firms perform better when economies of scale and mass production efficiencies dominate; though resource-partitioning may imply that there is a rise in the failure rates of generalist firms relative to specialist firms (Hannan and Freeman, 1977; Brittain and Freeman, 1980; Carroll, 1985, 1987)

are posited differ substantially. Early theoretical work in this area (Mueller and Tilton, 1969) proposed that high technical uncertainty early in an industry's history make R&D efforts experimental and on a small scale. Small firms are thus able to enter and compete technologically, since large firms do not hold a scale advantage. The expectation of positive profits from successful innovation spurs entry. The technology management literature makes similar arguments, focusing on the need for small-scale experimentation to uncover user preferences (e.g., Utterback and Abernathy, 1975; Abernathy and Utterback, 1978).

Evolutionary economists attribute entry to favorable information conditions early on. Gort and Klepper (1982) distinguish between 'type 1 information' – the knowledge of an industry's incumbents – and 'type 2 information', which emanates from sources external to an industry. They propose that in the initial stages of an industry's evolution, external type 2 information exceeds type 1 information, encouraging entry that exploits the external information sources. In later stages, when innovations stem from type 1 sources, incumbents have the advantage of learning by doing and established, familiar routines. Similarly, Winter (1984) identifies two regimes in an industry's evolution. Conditions under the 'entrepreneurial regime' are favorable to innovative entry, since the sources of knowledge critical to generating radical innovations lie outside established routines. In contrast, under the 'routinized regime', conditions favor incumbent innovation over innovative entry, because knowledge has accumulated in firm routines and a pattern of innovation has deepened. Shane (2001) documents the importance of technological regime empirically, in his analysis of whether a university licenses a new technology to a start-up rather than to an established firm for commercialization

Finally, from the perspective of organization ecology, social processes explain entry. Initially the increasing number of firms in an industry (density) enhances the social and political legitimacy of the population, enabling an inflow of resources that further increases new entries (foundings; see Hannan and Freeman, 1987). Different types of legitimization processes have been emphasized in the literature, including the effects of regulation (Dobbin and Dowd, 1997; Wade, Swaminathan, and Saxon, 1998), labor unions (Haveman and Cohen, 1994), resource availability (Carroll and Delacroix, 1982), social processes (Carroll and Swaminathan, 2000), and cultural images and frames (Hannan *et al.*, 1995).

What drives shakeouts? In addition to the wave of entry, the shakeout in the number of firms is a consistent observation in all three literature streams. However, there is little consensus on what causal factors underlie this empirical regularity. Technology management scholars, notably Utterback and colleagues, attribute shakeouts to the establishment of dominant designs (Abernathy and Utterback, 1978, Utterback and Suarez, 1993). A dominant design enables standardization of product design in an industry and marks the end of experimentation. A reinforcing loop relationship between a dominant design and the development of collateral assets implies that firms have an incentive to achieve economies of scale and to invest in process innovation and process integration, and that the minimum efficient scale of production increases as a result (Utterback and Suarez, 1993). Thus, these scholars theorize that firms that are unable to transition to the dominant design in their industry or are unable to change their structures and practices to fit the new evolutionary stage will either exit or merge with the dominant firms in the industry; industry shakeout is the outcome (Utterback and Abernathy, 1975; Abernathy and Utterback, 1978; Suarez and Utterback, 1995).

Evolutionary economists have invoked formal models to explain shakeout, but they are split as to whether dominant designs are the cause or the effect of shakeouts (Jovanovic and MacDonald, 1994a, b; Klepper, 1996). Jovanovic and MacDonald (1994b), for instance, assume an industry has one basic innovation and one refinement of the initial innovation and that a new firm's ability or inability to implement the superior technology causes a shakeout. Their model implicitly invokes the idea of a dominant design: firms that are unable to transition to an industry's dominant design end up exiting the industry because of inefficiencies in production and inability to lower their price.

In contrast, Klepper (1996) develops a model showing that the dominant design can be the outcome of the shakeout process. He assumes that firms with different technologies enter an industry and initially compete on the basis of both product and process innovation. Product innovation, which occurs through R&D, is subject to increasing returns, so larger firms are more efficient at it. Early stages of the industry life cycle are characterized by low start-up costs, thus enabling entry, particularly for firms armed with product innovations. However, the advantage of incumbents over entrants increases over time, given incumbent efforts to grow and their investments in R&D activities related to process innovations. The downward pressure on price that these competitive forces place causes both an increase in the threshold level of product innovation expertise for profitable entry and a shakeout survived by only the more efficient firms (Klepper, 1996). Thus, an important implication of Klepper's model is that an increase in entry barriers during shakeouts decreases variation in product design, and hence a dominant design emerges.

Other evolutionary economics models are noncommittal regarding whether shakeouts and dominant designs are causes or effects, and instead focus on underlying changes in industries' technological regimes (Winter, 1984) and on selection processes as causes of shakeouts. Drawing on Schumpeter's distinction between 'Mark I' (Schumpeter, 1911) and 'Mark II' (Schumpeter, 1950) periods of innovation, Nelson and Winter (1982) and Winter (1984) contend that as a technological regime changes from entrepreneurial to routinized, industry, conditions favor incumbent innovation over entrants (this distinction is similar in spirit to Gort and Klepper's (1982) distinction between sources of innovation and information). The resulting accumulation of knowledge in firm routines and a deepening pattern of innovation favors larger firms that emphasize process innovation and economies of scale, thus causing the selection of the more efficient firms and the exit of firms that are unable to withstand the competitive pressures (Breschi, Malerba, and Orsenigo, 2000).

Finally, organization ecologists attribute shakeouts to a shifting balance between the forces of legitimization and competition (Hannan, 1986; Hannan and Freeman, 1989; Carroll and Hannah, 1989). The intensity of competition increases at an increasing rate with population density, and the effects of competition soon overshadow the effects of legitimacy. The competitive pressures of an increasing population of firms causes resource scarcity, so that as population density increases beyond a certain level, a shakeout occurs because of the simultaneous decrease in foundings and increase in exits. In addition to the effects of contemporaneous density highlighted by the early ecology models, the effects of founding density are highlighted in subsequent models as explanations for decline in numbers of firms and increases in market concentration. Based on the notion of imprinting (Stinchcombe, 1965), these models propose that a firm's probability of failure is affected not only by contemporaneous density, but also by density at the time of its founding (Carroll and Hannan, 1989). Since organizations are shaped by the environment at their times of entry, 'founding density' is positively related to failure rates, and shakeouts occur because firms that entered during times of resource scarcity exit.

What drives a dominant design? Since the emergence of a dominant design is not a key part of the explanation for patterns of entry and exit for organizational ecologists, these scholars do not address the forces that drive convergence on a dominant design. Scholars in the technology management and evolutionary economics literatures, however, agree that a dominant design is not necessarily the technologically best solution. Utterback and Suarez (1993) describe it as the synthesis of features and innovations from prior product variants, and Anderson and Tushman (1990) specifically hypothesize that a dominant design is not the most technologically advanced variant. But if technical superiority does not drive outcomes, what does? By what selection process does a particular dominant design emerge?

Van de Ven and Garud (1993) propose a social system framework for understanding the emergence of technology. They identify three broad domains that interact to guide technological selection:

- institutional factors, such as standards, rules, and regulations;
- resource endowments, including financing and labor for research along a particular technological path;
- technical economic activities, primarily firm activities such as applied research, manufacturing, and sales.

In related work, Garud and Rappa (1994) focus on how the evaluation routines applied to new technologies will select out specific variants. They propose that the interaction among beliefs about a technology, evaluation routines, and technological artifacts, or products, drive technological evolution. One important element of an institutional environment is the set of technical communities that develop around different technologies. Rosenkopf and Tushman (1998) show how the co-evolution of technology and associated community networks resulted in the eventual dominance of one type of flight simulator – flight training devices – over the alternative, full flight simulators. Finally, Kaplan and Tripsas (2008) propose that along with the social, political, institutional, and economic factors considered by others, cognitive forces also drive an industry towards a dominant design. Producers, users, and other stakeholders interact to develop a common set of beliefs about what the product is and how it will be used.

As discussed above, evolutionary economists have developed models that show a dominant design is either the cause of a shakeout (Jovanovic and MacDonald, 1994b) or the outcome of a shakeout (Klepper, 1996). Other economists focus on the role of increasing returns to scale resulting from network externalities in driving markets to tip towards one dominant standard (e.g., Farrell and Saloner, 1986; Arthur, 1989). Although related to the literature on the technology life cycle, the standards literature is not reviewed here in depth. Excellent reviews include David and Steinmueller (1994) and Matutes and Regibeau (1989).

Who has a higher probability of survival and why? Although technology management scholars have not invested a great deal of effort in investigating the determinants of firm survival, this is a subject of intense interest to organizational ecologists and evolutionary economists. Once again, though, attributions of the causes of differences in firm survival diverge significantly.

Continuing the emphasis placed on dominant designs, technology management scholars attribute survival probabilities to the timing of firm entry relative to the establishment of a dominant design. Suarez and Utterback (1995) hypothesize that firms entering before that point have better chances of survival, because their early entry lets them accumulate collateral assets and benefit from experimentation. These pre-dominant-design entrants can shape the development of the dominant design and also profit from economies of scale and the creation of barriers to entry/mobility. Suarez and Utterback (1995) propose that the earlier firms enter relative to the onset of a dominant design, the higher are their probabilities of survival.

Evolutionary economists who examine the determinants of firm survival emphasize forces related to the underlying innovative activity and the source of information, consistent with their causal attribution for other empirical regularities. Like technology management and organizational ecology, this literature stream also theorizes timing of entry as an important determinant of survival; furthermore, it theorizes that emergence/growth stage entrants have a higher probability of survival than later entrants. Agarwal and Gort (1996) hypothesize that early entrants have the advantage of being the source of innovation in an industry and that they also benefit from a growth in demand. Developing this theory further, Klepper and Simons (2000a) discuss the role of superior capabilities possessed by diversifying entrants from industries related to the one they are entering. Since firms that operate in related industries have knowledge that is relevant for a focal industry, they enter earlier and harness their pre-existing resources for a survival (and market share) advantage. In addition, they innovate at higher rates than other firms, causing them to have a 'dominance by birthright' (Klepper and Simons, 2000a).

Importantly, although evolutionary economics studies show that firm and industry attributes that are found to affect probabilities of survival in cross-sectional studies also matter in evolutionary studies, they also indicate that life cycle stage conditions these relationships. This theory is based on the idea that entry barriers may also be survival barriers and that structural changes in competitive conditions interact with firm heterogeneity to differentiate survival probabilities (Agarwal, Sarkar, and Echambadi, 2002).

As with the other empirical regularities, organizational ecologists continue to emphasize the role of density dependence in determining firm survival. In keeping with the change role of legitimization and competition, these researchers theorize that firms that enter an industry in periods of resource munificence perform better than firms that enter in periods of resource scarcity (Hannan and Freeman, 1989; Hannan and Carroll, 1992). Thus, firms that enter or compete in periods of low competitive density have a higher survival probability than firms that enter or compete when the number of firms in the industry is high.

Finally, organizational ecologists also advance the resource-partitioning theory to explain differences in the probability of survival in the mature stages of an industry (Carroll, 1985). According to this theory, in environments characterized by a few generalist firms competing directly with each other in the 'center of the market', freed-up peripheral resources enable specialist firms to occupy niches. As a result of this resource partitioning, the theory predicts, more generalists and fewer specialists will fail (Carroll, 1985, 1987). A study by Khessina and Carroll (2002) examined how firms with different capabilities compete across different technological niches in the optical disk drive industry. They found that startups competed in the latest technological areas, while diversifying firms and incumbents are more evenly spread out, a result consistent with findings by Bayus and Agarwal (2007) in the personal computer industry.

Directions for Future Research

Combining these perspectives raises interesting research questions going forward. In some cases, these perspectives offer complementary explanations that enhance our understanding of the phenomena of interest here. In other cases, additional work is needed to tease out the contingencies that might reconcile conflicting perspectives.

One common theme in all three streams of literature, but particularly in the organization ecology and evolutionary economics perspectives, is the primacy of selection over adaptation. Organizational ecology originated because researchers wanted to identify environmental conditions rather than factors related to adaptation in determining failure rates (Hannan and Freeman, 1987, 1988). Ironically, although many evolutionary economists have implicitly moved away from the traditional structure-conduct-performance paradigm and the hypothesis of equilibrium when describing industry-level phenomena, they have done the opposite when theorizing about firm performance; their models of firm survival all focus on implications of life cycle stage conditions for firm advantages and performance. To be fair, each literature stream does attribute overall industry trends to the underlying firm conduct in terms of entry and exit from a focal industry, but there is scant attention to the conduct of firms while they are still in existence. Interestingly, several scholars examine firm evolution in parallel, with several of these studies using Nelson and Winter (1982) as a base. For example, Helfat and Peteraf (2003) examine the capability life cycle of firms. An important area of future research will be to look at firm and industry evolution together and examine how one may affect the other. Several industry evolution studies have highlighted the role of diversifying entrants, and therefore potentially fruitful research avenues relate to linking firm strategic renewal efforts with entrepreneurial entry and creation of new industries and markets.

Another important question going forward is how life cycle dynamics differ by geographic region. How can studies of national innovation systems (e.g., Nelson, 1993) inform our understanding of industry-level phenomena? With the exception of Chesbrough (1999) and Murmann (2003), very little comparative work exists in this field. Chesbrough (1999) finds that, in contrast to Christensen and Bower's (1996) analysis of US disk drive firms, Japanese disk drive firms were not displaced by new entrants, despite successive waves of disruptive technological change. Chesbrough attributes these differing fates to variations in institutional factors – in particular, labor mobility, access to venture capital, and particular buyer-supplier relationships. Murmann's (2003) detailed analysis of the synthetic dye industry in several nations shows significant differences in institutional contexts, entry and exit patterns, and innovation patterns. Although all the countries display an inverted U-shaped curve for the number of firms over time, the timing and magnitude of the peaks differ. These results raise a number of interesting questions. Do industry life cycle patterns generally differ across countries? What are the contingencies? In what situations do specific institutional factors matter more or less? How can firms take advantage of country differences in managing innovation portfolios?

Another area for future inquiry relates to level of analysis. Although much of the technology life cycle work has defined dominant designs at the system level, standardization of subsystems is also crucial. In fact, Tushman and Murmann (1998) propose that the concept of a dominant design may be more appropriately applied at the subsystem level. Relating the work on dominant designs to the literature on modularity (e.g., Baldwin and Clark, 2000) is therefore an important future step. For instance, interdependencies among system modules can affect the attractiveness of different technological alternatives as well as their evolutionary paths. Fixed landing gear for airplanes had worse aerodynamic performance than retractable gear, but Northrop created an innovative wing structure whose performance was compromised by retractable gear. Northrop therefore continued to experiment with fixed landing gear even after much of the industry had moved away from it (Vincenti, 1994). In this example, Northrop controlled both the wing and landing gear design choices. In many cases, however, different firms control different modules (Staudenmayer, Tripsas, and Tucci, 2005), raising a number of questions. Does the level of product modularity shift over the industry life cycle? Specifically, how does the level of inter-firm modularity change over time? Related questions address the level of vertical integration. How does vertical integration change over the industry life cycle? Are vertically integrated firms at an advantage during any particular stage?

Similarly, whereas in the past industry evolution studies have primarily focused on firms or industries as their units of analysis, future research could examine the role of *people*, particularly entrepreneurial founders, in greater depth. There have been some recent studies (Klepper 2002a, b, 2007; Agarwal *et al.*, 2004) on the issue, but much work still needs to be done on how people may be the fountainheads of innovation and may bring about both the emergence of new industries and their subsequent growth.

References

Abernathy, W.J. (1978). *The productivity dilemma*. Baltimore, MA: Johns Hopkins University Press.

Abernathy, W.J., and Clark, K.B. (1985). Innovation: mapping the winds of creative destruction. *Research Policy*, 14, 3–22.

Abernathy, W.J., Clark, K.B., and Kantrow, A.M. (1983). *Industrial renaissance: producing a competitive future for America*. New York: Basic Books.

Abernathy, W.J., and Utterback, J.M. (1978). Patterns of industrial innovation. *Technology Review*, 80(7), 40–7.

Adner, R., and Levinthal, D. (2001). Demand heterogeneity and technology evolution: implications for product and process innovation. *Management Science*, 47(5), 611–28.

Agarwal, A. (1998). Small firm survival and technological activity. *Small Business Economics*, 11(3), 215–24.

Agarwal, A., and Bayus, B. (2002). The market evolution and take-off of new product innovations. *Management Science*, 48(8), 1024–41.

Agarwal, A., and Bayus, B. (2004). Creating and surviving in new industries. In J.A.C. Baum and A.M. McGahan (eds), *Business Strategy over the Industry Life Cycle*, Volume 21, Oxford UK: JAI/Elsevier, 107–130.

Agarwal, A., Echambadi, R., Franco, A., and Sarkar, M. (2004). Knowledge transfer through inheritance: spin-out generation, development and survival. *Academy of Management Journal*, 47(4), 501–23.

Agarwal, A., and Gort, M. (1996). The evolution of markets and entry, exit and survival of firms. *Review of Economics and Statistics*, 78(3), 489–98.

Agarwal, A., and Gort, M. (2001). First mover advantage and the speed of competitive entry: 1887–1986. *Journal of Law and Economics*, 44(1), 161–78.

Agarwal, R., Sarkar, M., and Echambadi, R. (2002). The conditioning effect of time on firm survival: an industry life cycle approach. *Academy of Management Journal*, 45(5), 971–94.

Ahuja, G., and Katila, R. (2001). Technological acquisitions and the innovation performance of acquiring firms: a longitudinal study. *Strategic Management Journal*, 22(3), 197–220.

Aitken, H.G.J. (1985). *The continuous wave: technology and American radio, 1900–1932*. Princeton, NJ: Princeton University Press.

Anderson, P.C., and Tushman, M. (1990). Technological discontinuities and dominant designs: a cyclical model of technological change. *Administrative Science Quarterly*, 35(4), 604–33.

Arthur, W.B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *The Economic Journal*, 99, 116–31.

Audretsch, D.B. (1991). New-firm survival and the technological regime. *The Review of Economics and Statistics*, 73(3), 441–50.

Audretsch, D.B. (1995). *Innovation and industry evolution*. Cambridge, MA: MIT Press.

Baldwin, C., and Clark, K.B. (2000). *Design rules: the power of modularity*. Boston, MA: Harvard Business School Press.

Barnett, W.P. (1990). The organizational ecology of a technological system. *Administrative Science Quarterly*, 35(1), 31–60.

Barron, D.N., West, E., and Hannan, M.T. (1994). A time to grow and a time to die: growth and mortality of credit unions in New York City, 1914–1990. *American Journal of Sociology*, 100, 196–241.

Basalla, G. (1988). *The evolution of technology.* New York: Cambridge University Press.
Bass, F. (1969). A new product growth model for consumer durables. *Management Science,* 15(5), 215–27.
Bass, F.M. (1995). Empirical generalizations and marketing science – a personal view. *Marketing Science*, 14(3), G6–G19.
Baum, J.A.C., and Amburgey, T.L. (2002). Organizational ecology. In J.A.C. Baum (ed.), *The Blackwell Companion to Organizations*: Malden, MA: Blackwell, 304–26.
Baum, J.A.C., Korn, H.J., and Kotha, S. (1995). Dominant designs and population dynamics in telecommunications services: founding and failure of facsimile transmission service organizations, 1965–1992. *Social Science Research*, 24(2), 97–135.
Baum, J.A.C., and Oliver, C. (1991). Institutional linkages and organizational mortality. *Administrative Science Quarterly*, 36(2), 187–218.
Bayus, B.L. (1992). The dynamic pricing of next generation consumer durables. *Marketing Science*, 11(3), 251–65.
Bayus, B.L., and Agarwal, R. (2007). The role of pre-entry experience, entry timing and product technology strategies in explaining firm survival. *Management Science*, 53, 1887–1902.
Benner, M.J., and Tushman, M. (2002). Process management and technological innovation: a longitudinal study of the photography and paint industries. *Administrative Science Quarterly,* 47(4), 676–706.
Benner, M.J., and Tushman, M.L. (2003). Exploitation, exploration, and process management: The productivity dilemma revisited. *Academy of Management Review*, 28(2), 238–56.
Breschi, S., Malerba, F., and Orsenigo, L. (2000). Technological regimes and Schumpeterian patterns of innovation. *The Economic Journal*, 110(463), 388–410.
Brittain, J.W., and Freeman, J. (1980). Organizational proliferation and density dependent selection. In R.M.J. Kimberly & Associates (ed.), *The Organizational Life Cycle*. San Francisco: Jossey-Bass, 291–338.
Bruderl, J., and Schussler, R. (1990). Organizational mortality: the liability of newness and adolescence. *Administrative Science Quarterly*, 35, 530–47.
Carroll, G.R. (1985). Concentration and specialization: dynamics of niche width in populations of organizations. *American Journal of Sociology*, 90(6), 1262–83.
Carroll, G.R. (1987). Organizational approaches to strategy – an introduction and overview. *California Management Review*, 30(1), 8–10.
Carroll, G.R., Bigelow, L.S., Seidel, M-D.L., and Tsai, L.B. (1996). The fates of De Novo and De Alio producers in the American automobile industry 1885–1981. *Strategic Management Journal*, 17, 117–37.
Carroll, G. and Delacroix, J. (1982). Organizational mortality in the newspaper industries of Argentina and Ireland: an ecological approach. *Administrative Science Quarterly*, 27(2), 169–98
Carroll, G.R., and Hannan, M.T. (1989). Density delay in the evolution of organizational population. *Administrative Science Quarterly*, 34(3), 411–30.
Carroll, G.R., and Swaminathan, A. (2000). Why the microbrewery movement? Organizational dynamics of resource partitioning in the U.S. brewing industry. *The American Journal of Sociology*, 106(3), 715–62.
Cefis, E., and Marsili, O. (2005). A matter of life and death: innovation and firm survival. *Industrial and Corporate Change*, 14(6), 1167–92.
Chesbrough, H. (1999). *Assembling the elephant: a review of empirical studies on the impact of technical change upon competing firms.* In R. Burgleman and H.W. Chesbrough (eds), *Comparative Technological Evolution: Towards a Global Understanding of Innovation*, Volume 7, Amsterdam: Elsevier.
Christensen, C.M., and Bower, J.L. (1996). Customer power, strategic investment, and the failure of leading firms. *Strategic Management Journal*, 17, 197–218.

Christensen, C.M., Suarez F.F., and Utterback, J.M. (1998). Strategies for survival in fast-changing industries. *Management Science*, 44(12), S207–S221.
Clark, K.B. (1985). The interaction of design hierarchies and market concepts in technological evolution. *Research Policy*, 14(12), 235–51.
Cooper, A., and Schendel, D. (1976). Strategic responses to technological threats. *Business Horizons*, 19, 61–9.
Cusumano, M.A., Mylonadis, Y., and Rosenbloom, R.S. (1992). Strategic maneuvering and mass-market dynamics: the triumph of VHS over Beta. *Business History Review*, 66(1), 51–94.
David, P.A. (1992). Heroes, herds and hysteresis in technological history: Thomas Edison and 'The Battle of the Systems' reconsidered. *Industrial and Corporate Change*, (1), 129–80.
David, P.A., and Steinmueller, W.E. (1994). Economics of compatibility standards and competition in telecommunication networks. *Information Economics and Policy*, 6(3–4), 217–41.
Dobbin, F.J.R, and Dowd, T. (1997). How policy shapes competition: early railroad foundings in Massachusetts. *Administrative Science Quarterly*, 42(3), 501–29.
Dobrev, S.D., Kim, T-Y., and Carroll, G.R. (2003. Shifting gears, shifting niches: organizational inertia and change in the evolution of the U.S. automobile industry, 1885–1981. *Organization Science*, 14(3), 264–82.
Dowell, G., and Swaminathan, A. (2006). Entry timing, exploration, and firm survival in the early U.S. bicycle industry. *Strategic Management Journal*, 27(12), 1159–82.
Farrell, J., and Saloner, G. (1986). Installed base and compatibility: innovation, product preannouncements, and predation. *The American Economic Review*, 76(5), 940–55.
Fichman, M., and Levinthal, D.A. (1991). Honeymoons and the liability of adolescence: a new perspective on duration dependence in social and organizational relationships *Academy of Management Review*, 16, 442–68.
Filson, D. (2001). The nature and effects of technological change over the industry life cycle. *Review of Economic Dynamics*, 4, 460–94.
Freeman, J., Carroll, G.R., and Hannan, M.T. (1983). The liability of newness: age dependence in organizational death rates. *American Sociological Review*, 48(5), 692–710.
Garud, R., and Rappa, M.A. (1994). A socio-cognitive model of technology evolution: the case of cochlear implants. *Organizational Science*, 5(3), 344–62.
Gilbert, C. (2005). Unbundling the structure of inertia: resource versus routine rigidity. *Academy of Management Journal*, 48(5), 741–63.
Golder, P.N., and Tellis, G.J. (1997). Will it every fly? modeling the takeoff of really new consumer durables. *Marketing Science*, 16(3), 256–70.
Gort, M., and Klepper, S. (1982). Time paths in the diffusion of product innovations. *The Economic Journal*, 92(367), 630–53.
Hannan, M.T. (1986). Competitive and institutional process in organizational ecology. In M.T. Hannan (ed.). Technical report, Department of Sociology, Cornell University: Ithaca, NY.
Hannan, M.T., and Carroll, G.R. (1992). *Dynamics of organizational populations: density, competition, and legitimation*. New York: Oxford University Press.
Hannan, M.T., Carroll, G.R., Dundon, E.A., and Torres, J.C. (1995). Organizational evolution in a multinational context: entries of automobile manufacturers in Belgium, Britain, France, Germany, and Italy – comment/reply. *American Sociological Review*, 60(4), 509–28.
Hannan, M., and Freeman, J. (1977). The population ecology of organizations. *American Journal of Sociology*, 82, 929–64.
Hannan, M.T., and Freeman, J. (1987). The ecology of organizational founding – American Labor Unions, 1836–1985. *American Journal of Sociology*, 92(4), 910–43.
Hannan, M.T., and Freeman, J. (1988). Density dependence in the growth of organizational populations. In G. Carroll (ed.), *Ecological Models of Organizations*, Cambridge, MA: Ballinger Books, 7–32.

Hannan, M., and Freeman, J. (1989). *Organizational ecology*. Cambridge, MA: Harvard University Press.

Haveman, H.A., and Cohen, L.E. (1994). The ecological dynamics of careers: the impact of organizational founding, dissolution, and merger on job mobility. *The American Journal of Sociology*, 100(1), 104–52.

Helfat, C.E., and Lieberman, M.B. (2002). The birth of capabilities: market entry and the importance of pre-history. *Industrial and Corporate Change*, 11(4), 725–60.

Helfat C.E., and Peteraf, M.A. (2003). The dynamic resource-based view: capability lifecycles. *Strategic Management Journal*, 24(10), 997–1010.

Henderson, R., and Clark, K.B. (1990). Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, 35(1), 9–30.

Henderson, R.M. (1993). Underinvestment and incompetence as responses to radical innovation: evidence from the photolithographic alignment equipment industry. *The Rand Journal of Economics*, 24(2), 248–70.

Iansiti, M., and Khanna, T. (1995). Technological evolution, system architecture and the obsolescence of firm capabilities. *Industrial and Corporate Change*, 4(2), 333–61.

Jenkins, R. (1975). *Images and enterprise*. Cambridge, MA: Harvard University Press.

Jovanovic, B., and MacDonald, G.M. (1994a). Competitive diffusion. *The Journal of Political Economy*, 102(1), 24–52.

Jovanovic, B., and MacDonald, G.M. (1994b). The life cycle of a competitive industry. *The Journal of Political Economy*, 102(2), 322–47.

Kaplan, S., and Tripsas, M. (2008). Thinking about technology: applying a cognitive lens to technical change. *Research Policy*, 37(5), 790–805.

Katila, R. (2002). New product search over time: past ideas in their prime? *Academy of Management Journal*, 45(5), 995–1010.

Khessina, O.M. (2003). Entry mode, technological innovation and firm survival in the worldwide optical diskdrive industry, 1983–1999. Ph.D. Thesis, University of California at Berkeley, Berkeley, CA.

Khessina, O.M., and Carroll, G.R. (2002). Product dynamics of denovo and dealio firms in the worldwide optical disk drive industry, 1983–1999. *Paper presented at the Academy of Management Meetings*: Denver, CO.

King, A.A., and Tucci, C.L. (2002). Incumbent entry into new market niches: the role of experience and managerial choice in the creation of dynamic capabilities. *Management Science*, 48(2), 171–86.

Klepper, S. (1996). Entry, exit, growth, and innovation over the product life cycle. *The American Economic Review*, 86(3), 562–83.

Klepper, S. (1997). Industry life cycles. *Industrial and Corporate Change*, 6(1), 145–81.

Klepper, S. (2002a). The capabilities of new firms and the evolution of the US automobile industry. *Industrial and Corporate Change*, 11(4), 645–66.

Klepper, S. (2002b). Firm survival and the evolution of oligopoly. *RAND Journal of Economics*, 33(1), 37–61.

Klepper, S., and Graddy, E. (1990). The evolution of new industries and determinants of market structure. *RAND Journal of Economics*, 21(1), 27–44.

Klepper, S., and Miller, J.H. (1995). Entry, exit, and shakeouts in the United States in new manufactured products. *International Journal of Industrial Organization*, 13(4), 567–91.

Klepper, S., and Simons, K.L. (1997). Technological extinctions of industrial firms: an inquiry into their nature and causes. *Industrial and Corporate Change*, 6(2), 1–82.

Klepper, S., and Simons, K.L. (2000a) Dominance by birthright: entry of prior radio producers and competitive ramifications in the U.S. television receiver industry. *Strategic Management Journal*, 21(10/11), 997–1016.

Klepper, S., and Simons, K.L. (2000b). The making of an oligopoly: firm survival and technological change in the evolution of the U.S. tire industry. *The Journal of Political Economy*, 108(4), 728–60.

Klepper, S., and Simons, K.L. (2005). Industry shakeouts and technological change. *International Journal of Industrial Organization*, 23, 23–43.

Klepper, S. (2007). Disagreements, spinoffs, and the evolution of Detroit as the capital of the U.S. automobile industry. *Management Science*, 53(4), 616–31.

Levinthal, D. (1998). The slow pace of rapid technological change: gradualism and punctuation in technological change. *Industrial and Corporate Change*, 7(2), 217–47.

Lieberman, M.B. (1990). Exit from declining industries: 'Shakeout' or 'Stakeout'? *RAND Journal of Economics*, 21(4), 538–54.

Mahajan, V., Muller, E., and Bass, F.M. (1990). New product diffusion models in Marketing: a review and directions for research. *Journal of Marketing*, 54(1), 1–26.

Matutes, C., and Regibeau, P. (1989). Standardization across markets and entry. *The Journal of Industrial Economics*, 37(4), 359–71.

McGahan, A.M., and Silverman, B.S. (2001). How does innovative activity change as industries mature? *International Journal of Industrial Organization*, 19(7), 1141–60.

McKendrick, D.G., and Carroll, G.R. (2001). On the genesis of organizational forms: evidence from the market for disk arrays. *Organization Science*, 12(6), 661–82.

Mitchell, W. (1989). Whether and when? Probability and timing of incumbents' entry into emerging industrial subfields. *Administrative Science Quarterly*, 34, 208–30.

Mitchell, W. (1991). Dual clocks: entry order influences on incumbent and newcomer market share and survival when specialized assets retain their value. *Strategic Management Journal*, 12, 85–100.

Moore, G. (1991). *Crossing the chasm*. New York: Harper Collins.

Mueller, D.C., and Tilton, J.E. (1969). Research and development costs as a barrier to entry. *The Canadian Journal of Economics*, 2(4), 570–79.

Murmann, J.P. (2003). *Knowledge and competitive advantage: the coevolution of firms, technology, and national institutions*. New York: Cambridge University Press.

Myers, S., and Marquis, D.G. (1969). *Successful industrial innovations: a study of factors underlying innovation in selected firms*. Washington DC: National Science Foundation.

Nelson, R.R. (1993). *National innovation systems: a comparative analysis*. New York: Oxford University Press.

Nelson, R.R., and Winter, S. (1982). *An evolutionary theory of economic change*. Cambridge, MA: Harvard University Press.

Noble, D. (1984). *Forces of production*. New York: Knopf.

O'Reilly, C. and Tushman, M.L. (2008). Ambidexterity as a dynamic capability: resolving the innovator's dilemma. *Research in Organizational Behavior*, 28, 185–206.

Rogers, E.M. (1995). *Diffusion of innovations*. New York: Free Press.

Rosenkopf, L., and Tushman, M. (1994). The coevolution of technology and organization. In J.A.C. Baum and J. Singh (eds), *Evolutionary Dynamics of Organizations*. New York: Oxford University Press.

Rosenkopf, L., and Tushman, M.L. (1998). The coevolution of community networks and technology: lessons from the flight simulation industry. *Industrial and Corporate Change*, 7(2), 311–46.

Rothaermel, F.T. (2001). Incumbent's advantage through exploiting complementary assets via interfirm cooperation. *Strategic Management Journal*, 22(6/7), 687–99.

Rothaermel, F.T., and Hill, C.W.L. (2005). Technological discontinuities and complementary assets: a longitudinal study of industry and firm performance. *Organization Science*, 16(1), 52–70.

Sarkar, M.B., Echambadi, R., Agarwal, R., and Sen, B. (2006). The effect of the innovative environment on exit of entrepreneurial firms. *Strategic Management Journal*, 27, 519–39.

Schumpeter, J. (1911) (1934). *The theory of economic development*. Harvard University Press: Cambridge, MA.

Schumpeter, J.A. (1950). *Capitalism, Socialism and Democracy*. New York: Harper & Row.

Shane, S. (2001). Technology regimes and new firm formation. *Management Science*, 47(9), 1173–90.

Singh, J.V., and Lumsden, C.J. (1990). Theory and research in organizational ecology. *Annual Review of Sociology*, 16, 161–95.

Staudenmayer, N., Tripsas, M., and Tucci, C. (2005). Interfirm modularity and the implications for product development. *Jounal of Product Innovation Management*, 22, 303–21.

Stinchcombe, A.L. (1965). Social structure and organizations. In J.G. March (ed.), *Handbook of Organizations*. Chicago, IL: Rand-McNally.

Stuart, T.E., and Podolny, J.M. (1996). Local search and the evolution of technological capabilities. *Strategic Management Journal* 17, (Special Issue: Evolutionary Perspectives on Strategy), 21–38.

Suarez, F. (2004). Battles for technological dominance: an integrative framework. *Research Policy*, 33(2), 271–86.

Suarez, F.F., and Utterback, J.M. (1995). Dominant designs and the survival of firms. *Strategic Management Journal*, 16(6), 415–30.

Sutton, J. (1997). Gibrat's legacy. *Journal of Economic Literature*, 35(1), 40–59.

Taylor, A., and Greve, H. (2006). Superman or the Fantastic Four? Knowledge combination and experience in innovative teams. *Academy of Management Journal*, 49(4), 723–40.

Teagarden, L., Echols, A., and Hatfield, D. (2000). The value of patience and start-up firms: a re-examination of entry timing for emerging markets. *Entrepreneurship Theory and Practice*, 24(4), 41–8.

Tripsas, M. (1997a). Surviving radical technological change through dynamic capability: evidence from the typesetter industry. *Industrial and Corporate Change*, 6(2), 341–77.

Tripsas, M. (1997b). Unraveling the process of creative destruction: complementary assets and incumbent survival in the typesetter industry. *Strategic Management Journal*, 18, 119–142.

Tripsas, M. (2008). Customer preference discontinuities: a trigger for radical technological change. *Managerial and Decision Economics*, 29, 79–97.

Tushman, M.L., and Anderson, P.C. (1986). Technological discontinuities and organizational environments. *Administrative Science Quarterly*, 31(3), 439–65.

Tushman, M., and Murmann, J.P. (1998). Dominant designs, technology cycles, and organizational outcomes. *Research in Organizational Behavior*, 20, 231–66.

Tushman, M.L., and Rosenkopf, L. (1992). On the organizational determinants of technological change: towards a sociology of technological evolution. In L. Cummings and B. Staw (eds), *Research in Organizational Behavior*, Vol. 14. Greenwich, CT: JAI Press, 311–47.

Utterback, J.M., and Abernathy, W.J. (1975). A dynamic model of process and product innovation. *Omega*, 3(6), 639–56.

Utterback, J.M., and Suarez, F.F. (1993). Innovation, competition, and industry structure. *Research Policy*, 22(1), 1–21.

Van de Ven, A.H., and Garud, R. (1993). Innovation and industry development: the case of cochlear implants. *Research on Technological Innovation, Management, and Policy*, 5, 1–46.

Van de Ven, A.H., and Garud, R. (1994). The coevolution of technical and institutional events in the development of an innovation. In J.A.C. Baum and J.V. Singh (eds), *Evolutionary Dynamics of Organizations*, New York: Oxford University Press, 425–43.

Vincenti, W.G. (1994). Variation-selection in the innovation of the retractable airplane landing gear: the Northrop 'anomaly'. *Research Policy*, 23(5), 575–82.

Wade, J. (1995). Dynamics of organizational communities and technological bandwagons: an empirical investigation of community evolution in the microprocessor market. *Strategic Management Journal (1986–1998)*, 16(Special Issue), 111–33.

Wade, J.B. (1996). A community-level analysis of sources and rates of technological variation in the microprocessor market. *Academy of Management Journal*, 39(5), 1218–44.

Wade, J.B., Swaminathan, A., and Saxon, M.S. (1998). Normative and resource flow consequences of local regulations in the American brewing industry, 1845–1918. *Administrative Science Quarterly*, 43(4), 905–35.

Winter, S.G. (1984). Schumpeterian competition in alternative technological regimes. *Journal of Economic Behavior & Organization*, 5(3–4), 287–320.