**Innovation, Competition, and
Industry Structure**

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How is changing product and process technology related to competition and industry structure? Although in recent years there has been increased interest in the subject (see, for instance, the work of the MIT Commission on Productivity, 1989), few scholars have examined the links between production processes and process improvements and productivity advances and competitiveness. Fewer still have looked at product technology or the relationships between product technology and their enabling processes and corporate strategy and competitiveness. Our contention is that these questions are central to understanding questions of larger scope such the long term success or failure of firms and even industries. Our purpose in this article is both to begin to explore the issues embedded in the dynamics of technological change and competitiveness and to present some evidence about patterns of innovation in products and processes at the firm level to follow in succeeding chapters. Just as the facets and geometry of a crystal reflect the microstructure, chemistry and physics of its constituent atoms and molecules, we believe that the competitive structure dynamics of an industry reflect underlying product and process technologies and innovations. Unlike a crystal the shapes taken by technological change or by industry structure are not necessarily predetermined as a superficial reading of our argument would suggest. Rather we contend only that choices made at one level are necessarily reflected at the other. For instance, greater degrees of competition will result in more rapid rates of technological change, while rapidly advancing technology and potentials for broadening application will attract entrants.

In earlier work Abernathy and Utterback introduced the concept of a dominant product design and suggested that the occurrence of a dominant design may alter the character of innovation and competition in a firm and

an industry. A dominant design usually takes the form of a new product (or set of features) synthesized from individual technological innovations introduced independently in prior product variants. A dominant design has the effect of enforcing or encouraging standardization so that production or other complementary economies can be sought. Then effective competition begins to take place on the basis of cost and scale as well as of product performance.

Similar dominant design milestones can be identified in many product lines. These often have the result of drastically reducing the number of performance requirements to be met by a product by making many features implicit in the dominant design and its increasing acceptance. Examples include the common typewriter keyboard, the RCA television standard and the three color black mask picture tube also devised by RCA, the simple four-function calculator and the integrated circuit computer memory chip in its successively larger manifestations. That dominant designs are not necessarily predetermined is easily illustrated by considering that the standard keyboard was designed to minimize the interference of mechanical typewriter keys, or by considering Sony's challenge to the RCA devised tube. A dominant design is generally the product of the experiments, technical possibilities, choices and proprietary positions of its day. Equally, the persistence of the older designs mentioned illustrates the momentum of both established practice and complementary assets such as typing skills and training. Once such a design is accepted it can have a profound impact on both the direction of further technical advance, on the rate of that advance, and on the structure of competition.

In this article we intend to explore the questions above by looking opportunistically at a series of examples arrayed over the past century. These

include typewriters, the automobile, television sets and picture tubes, transistors, integrated circuits, calculators and supercomputers. Data on industry participation and parallel data on technological change over the full course of an industry's development have been difficult to obtain. Thus, although our sample is not balanced or weighted in any scientific sense, it consists of the most complete sets of data that we have so far been able to discover or synthesize. More fragmentary data from other industries will be used to illustrate particular points. The data available do convincingly point to the fact that a dominant design and product standardization mark a watershed in industry structure and competition in each case examined. In all but the first case (typewriters) and the last (massively parallel computers) information on product technology and industry participation have been derived from independent sources. To date our investigations have been limited to assembled products and essentially to the United States.

Hypotheses

We suggest that creative synthesis of a new product innovation by one or a few firms results in a temporary monopoly situation, high unit profit margins and prices, and sales of the innovation in those few market niches where it possesses the greatest performance advantage over other competing alternatives. As volume of production and demand grows, and as a wider variety of applications is opened for the innovation, many new firms enter the market with diverse variations of the product. For example, early versions of the automobile included steam and electric vehicles as well as the now familiar internal-combustion engine.

The appearance of a dominant design shifts the competitive emphasis to favor those firms with a greater skill in process innovation and process integration, and with more highly developed internal technical and engineering skills. Many firms will be unable to compete effectively and will fail. Others may possess special resources and thus successfully merge with the ultimately dominant firms. Some weaker firms may merge and still fail.

Eventually, we believe that in general the market reaches a point of stability, in which there are only a few firms having standardized or slightly differentiated products and relatively stable sales and market shares.¹ A few small firms may remain in the industry, serving specialized market segments, but, as opposed to the small firms entering special segments early in the industry, they have little growth potential. Thus, it is important to distinguish between merely small firms and small firms which are new entrants, and to keep in mind that the term new entrants includes existing firms (large or small) moving from their established market or technological base into a new product area.

Mueller and Tilton 1969 were among the first to present this hypothesis in its entirety. They contend that a new industry is created by the occurrence of a major process or product innovation and develops technologically as less radical innovations are introduced. They further argue that the large corporation seldom provides its people with incentives to initiate a development of radical importance; thus, these changes tend to be developed by new entrants without an established stake in a product market segment. In their words, neither large absolute size nor market power

¹ The successful entry of large Japanese firms into mature industries in the last few decades has provided a counter-example to this hypothesis. We discuss the Japanese strategy later on the paper.

appears to be a necessary condition for successful development of most major innovations.

Mueller and Tilton contend that once a major innovation is established, there will be a rush of firms entering the newly formed industry, or adopting a new process innovation. They hold that during the early period of entry and experimentation immediately following a major innovation, the science and technology upon which it depends is often only crudely understood, and that this reduces the advantage of large firms over others. However, Mueller and Tilton suggest that as the number of firms entering the industry increases and more and more R&D is undertaken on the innovation, research becomes increasingly specialized and innovations tend to focus on improvements in small elements of the technology. This clearly works to the advantage of larger firms in the expanding industry and to the disadvantage of smaller entrants. Product differentiation will be increasingly centered around the technical strengths and R&D organization of the existing firms. Strong patent positions may have been established by earlier entering firms that are difficult for later entrants to completely circumvent.

Burton Klein (1977) suggests a profound connection between industry structure and technological change in his seminal work on dynamic economics. Klein portrays each firm's investments and product introductions as experiments which provide corrective and stimulating feedback to that firm and to the industry about product and market requirements. Thus, the earliest period in the development of a product line or industry in which few firms participate would necessarily be a period of relatively slow technical progress and productivity advance. As larger numbers of firms enter the arena, thus broadening the range of

experimentation and the definition of the product technology, Klein expects greater innovation with correspondingly greater technological progress and productivity advance. Finally, as a few firms come to dominate the industry due to superior product technology and productivity, both experimentation and progress will slow. Renewal or broadening of competition would seemingly be required for more rapid progress to recur. In reviewing earlier work Klein finds no case in which a major advance, one which established a new and more rapid trajectory for technological progress, came from a major firm in the industry in question. From this evidence he concludes that the process of moving from a dynamic organization to a static one, of going from a period of rapid organizational learning to a period of slow or no progress, appears to be highly irreversible.

We do not agree entirely with the idea that only small firms can be innovative in a young industry. Rather, instead of focusing on firm size, we contend that innovative firms often come from outside the industry in question (this argument is in line with the earlier work of Gilfillan 1935 and Schön 1966). Aside from that point, and more importantly, both this work and that of Mueller and Tilton and of Klein claim that as an industry stabilizes--that is, as technological progress slows down and production techniques become standardized--barriers to entry increase. The most attractive market niches will already be occupied. As process integration progresses, the cost of production equipment rises dramatically. Product prices and production costs will fall, so that firms with the largest market shares will be the ones to benefit from further expansion.

An existing distribution network may also be a powerful barrier to entry, particularly to foreign firms. However, a strong network may also be a disadvantage. Underwood, for example, thought that its position in the

market for business typewriters was secured by nearly one-thousand proprietary outlets. But when IBM entered this market with electric typewriters it was able to overwhelm Underwood's advantage by marketing through its 2300 office equipment dealerships. Similarly, when Sony introduced the transistor radio most radios were sold and repaired through manufacturers own distributorships and retail stores. Sony simply circumvented this seeming barrier by selling directly through mass merchandisers. Transistor radios were simply mailed to a repair center or replaced if problems were encountered.

Another hallmark of stability is a concerted drive among the surviving firms toward tightening the control over the value chain. This process has usually two dimensions: 1) an improvement in the relationships with suppliers and distributors, toward a more integrated and cooperative relationship; and 2) the pursuit of vertical integration, i.e. direct ownership of the different stages in the value chain. As for supplier relationships, the emergence of a set of more or less captive suppliers of equipment and components is commonplace. Such a set of suppliers further stabilizes the nature of competition, and creates yet another barrier to entry. Closer relationships with distributors have similar effects. Insofar as vertical integration is concerned, this can take the form of firms producing the final product reaching forward to distribution and marketing or reaching backward to furnish more of their own components, subassemblies and raw materials, or it may take the form of firms producing components reaching forward to do more of the assembly and production of final goods for the market. Such dramatic changes will clearly have ripple effects on firms which buy from or sell to the evolving set of competitors, as well as on firms attempting to enter the market.

All of these factors point to the hypothesis that large amounts of capital would be needed by a new firm entering at this point. Thus, it is no wonder that most radical innovations occur within new entrants attempting to break into an established set of competitors, rather than within firms whose capital and resources are tied up in the existing technology. Indeed, it is just at the point of stability that firms may become locked into narrow positions that may ultimately increase their vulnerability. An existing distribution network may suddenly be threatened by a new technology that requires sharply reduced servicing or maintenance, or by the entry of a large firm with an even stronger distribution network or a broader product line. Existing production management techniques may become superseded by more effective practices. An existing patent may expire. Mueller and Tilton contend that industries become stable when patent positions expire, and Klein contends that vertical integration tends to buffer larger firms from new competitors. Our hypothesis is that a period of stability in industry structure and market share is more likely to be a harbinger of invasion of the industry by a functionally superior but somewhat more costly technology. Following a period of stability a new wave of product and process change--or, in a few cases, the revitalization of the dominant technology itself via significant product improvement or the use of new production techniques and technology may be expected to occur.

In summary, we expect the development of a set of competitors to begin with a wave of entry gradually reaching a peak at about the time that the dominant design of the major product emerges, and then rapidly tapering off. This is followed by a corresponding wave of exits of firms from the industry. The sum of the two curves will yield the total number of participants in the product market segment at any point. This total curve will

usually start with a gentle rise representing the first few fluid productive units entering the business followed by a much sharper rise which represents a wave of imitating firms. The point at which a dominant design is introduced in the industry is expected to be followed by a rather sharp decline in the total number of participants until the curve of total participants reaches the stable condition with a few firms sharing the market.

Related Concepts

Other contemporary concepts in the field related to the model proposed here are those of technological paradigms and trajectories, technological guideposts, discontinuities, product design hierarchies, and notions from the population ecology literature. Let us discuss briefly how they relate to our work.

Population ecology predicts that the surviving organizations in a environment niche would be those best fitted to resist a process of "natural selection" (Hannan and Freeman 1977, Freeman 1982). If we consider business firms as the organizations in this theory and think of an industry as the environmental niche, population ecology predicts a strikingly similar pattern to the one proposed by our model.² In our terminology, the former model predicts a rapid increase in the number of firms at the beginning of the industry; a peak is reached later on and thereafter the population of firms declines. This is also what the model proposed here predicts. Indeed, the graphs based on data from the population ecology literature (see, for instance,

² The notion of an "industry" is always somewhat obscure, for its limits are difficult to define (this problem is also present, and perhaps more strongly, in the notion of niche). We think of an industry as composed by a product class, i.e. a group of similar products that serve the same market need and thus compete directly in the marketplace.

Carroll and Hannan, 1989) look much like the ones the reader will find in this paper.

There is one major difference between population ecology models and the one presented here, however. Population ecology, at least in its more strict presentations, assumes that organizational inertia is always present. Organizations do not change, they are selected out of a niche by better-fitted competitors. In contrast, organizational change is a hallmark of our model. For us, organizational change is driven by technological change in the industry. Organizations are not born to win or lose a natural selection process. Instead, some of them evolve through changes in their administrative and production structures triggered by technological change to become the surviving ones.

Other scholars have developed related concepts. Devendra Sahal, for instance, has coined the concept of "technological guideposts" (Sahal, 1985). For Sahal, technological change is characterized by technological guideposts, which are major advances in technology capable of setting a direction to be followed by more incremental developments. In his framework, technological guideposts are chosen (among many alternatives) essentially by chance. Only when a guidepost is established, the more rational, predictable process of advancement along the line set by the guidepost begins.

Giovanni Dosi, borrowing heavily from Kuhn's 1962 work on scientific advances, has proposed the concepts of "technological paradigms" and "technological trajectories" to refer to the same phenomenon (Dosi 1982). Roughly, a technological paradigm is a pattern of solution of selected technological problems. Technological paradigms define some idea of technological progress, i.e. they point out specific technological trajectories.

Technological trajectories are relatively minor technological developments along the pattern set by a paradigm.

Both Dosi's and Sahal's concepts are related to Nelson and Winter's notions of "technological regimes" and "natural trajectories," and to Clark's notion of "design hierarchies" (Nelson and Winter 1982, Clark 1985). The latter notion is the most closely related to the concepts of the model proposed here. In Clark's view, patterns of innovation are the result of the logic of problem solving in design and the formation of concepts underlying customer choice. Both processes are seen as imposing a hierarchical structure on the evolution of technology. The choice of a core technical concept (e.g. internal combustion engine in the auto industry) establishes an "agenda" for a product's technical development. Similarly, problem solving on the customer side also helps establish the agenda for technology development. The well-known model T, for instance, came into being not only because of the outcome of technical decisions made earlier by designers. It was also the result of the evolution of customers' awareness and preferences about automobiles, in particular the demand for a durable, reliable and low cost means of "basic transportation" (Abernathy 1978).

We also view the emergence of a dominant design as the result of the interplay between technical and market choices. Indeed, our notion of a dominant design can be represented using Clark's design hierarchies approach. We illustrate below a simplified case of a design hierarchy. A technological trajectory is the path of technical progress established by the choice of a core technical concept at the outset (there are two trajectories in the figure). A dominant design is the outcome resulting from a series of technical decisions about the product constrained by prior technical choices and by the evolution of customer preferences. A dominant design often does

not represent radical change, but the creative synthesis of the available technology and the existing knowledge about customers preferences. It may not be an ideal choice in a broader context of optimality, but rather a design, such as the familiar QWERTY typewriter keyboard, that becomes an effective standard. We now know how to design better keyboards, but the difficulties of moving from a well established trajectory to a different one can clearly be substantial.

Clark correctly points out that "radical" technological change will be associated with a movement up the design hierarchy, i.e. when existing core concepts are challenged. Along the same vein, the notions of technological paradigms and guideposts are easily associated with the well known concept of technological discontinuities (Martino 1980, Utterback and Kim 1986). In our view, technological discontinuities correspond to the origin of what we have called an industry (see footnote 2). The model we have outlined in the previous section holds for a given technological paradigm, guidepost, or

discontinuity. A new discontinuity is considered in our model as the beginning of a "new" industry. For instance, our data below only contain information for the mechanical typewriter industry. The advent of the electric typewriter, a discontinuity, changed completely the rules of the game for the mechanical typewriter firms. A new industry was born, which would also be subject to the postulates of our model.

Recently, Tushman and Anderson have borrowed the Abernathy-Utterback concept of dominant design and that of technological discontinuities to provide further evidence for the hypotheses considered here (Tushman and Anderson 1986, 1990). They have gathered valuable data on the minicomputer, glass, and cement industries and performed tests of the model. Their work not only provides more data to support the Abernathy-Utterback model, but also enhances the latter in several respects. They provide, for instance, additional insights on the emergence of dominant designs, by looking at this problem as the result of a political process (unfortunately, the authors do not fully explore this interesting idea). They also make an insightful distinction between competence-enhancing and competence-destroying discontinuities. The former type builds on existing know-how in the industry, while the latter one renders existing knowledge obsolete. Tushman and Anderson argue that each discontinuity type will have a different effect on the dynamics of competition in the industry.

We will now turn to a discussion of some specific examples which exhibit the waves of change our model predicts: the manual typewriter industry, the auto industry, the calculator, the semiconductor, the television, television tubes, and supercomputer business. We will then turn to the question of successive waves of entry, and again present specific examples that illustrate the applicability of the hypotheses presented in the previous

section. Though we have a rather small number of observations (industries), each example examined so far conforms in its major features to the hypotheses stated above.

The Typewriter

The typewriter industry began in 1873 with the entry of the Remington Arms Company. Their typewriter was a synthesis of many existing elements. Clockwork suggested the idea of the escapement (to move the carriage one letter at a time). A telegraph sender provided parts for the first model for keys and arms. A sewing machine pedal was used for returning the carriage. The piano contributed the concept of the free and swinging arms and hammers for imprinting the letters. The industry's initial growth was slow, and Remington had essentially a monopoly for the first few years. By 1885, the field had widened to five competitors. A period of rapid entry followed, and by the early 1890s, 30 firms had been established. Of these, Underwood and Smith were the principal innovators. Underwood, a supplier of ribbons and other typewriter materials, entered in 1895. Smith was a 1903 spin-off from the Remington Union Company with a product innovation--a visible, front strike typewriter--that was incompatible with the Remington product line.

In 1904, the Royal Typewriter Company, the last of the four firms which were to dominate the industry, was established. By 1909, almost 40 companies competed in the typewriter industry. Many others which entered and quickly exited, without making any significant penetration, have been left out of our records. Most of the actively competing firms were started between 1886-1899, forming the sharp wave of entry hypothesized.

The set of features which were to become the dominant design in the typewriter industry resulted from a fascinating sequence of major

innovations. In 1899, Underwood introduced the Model 5. The Model 5 had visible writing, rather than the page being obscured by the type. It was the first to have a tabulator as part of the typewriter, to be able to cut stencils, and to make copies; thus, it did not need expensive attachments to do most of the jobs encountered in the office and consequently won Underwood a large share of the market.

During the years following Underwood's introduction of the model 5, Edward Hess, a man with exceptional mechanical abilities, perfected many of the features that were still rough in model 5. By rearranging the clutter of knobs, bars, and ribbon mechanism, he was able to deliver "total, uncompromised visibility." He reversed the linkage in the typebar action, so the action was a pull rather than a push, thus saving energy. He removed much of the friction from the escapement--the toothwheel that links the keys with the carriage and moves it along one space when a letter is struck. These and other innovations gave Hess' typewriter a light, fast touch very welcomed by users. Hess received 140 typewriter patents during his lifetime. One of Hess' major concerns, and one that has direct implication for our model, was to reduce typewriter's production costs by improved design.

After Underwood's model 5 and Hess' innovations, competition centered mainly around features and increasingly on production costs. Figure one shows the pattern that our model predicts. The rapid growth in the number of firms halts in 1899, the same year when Underwood's model 5 was introduced. After 1906, when most of Hess' innovations were in place, the number of firms in the industry begins an irreversible decline. Incidentally, Underwood, which had been a major innovator with its model 5, lagged in bringing out new developments, and within a decade, had lost its dominant position to Royal.

The period between 1906-1940 was a period of rapid reduction in the total number of firms. By 1940, there were only five predominant producers: IBM and the four traditional firms. Each of the four--Remington, Royal, Smith and Underwood--had 20% of the market, with IBM having approximately 10%, and others (mostly foreign) 10%. The efficient size for a single plant was between 10% and 30% of total demand, or 150,000 to 450,000 units per year. Relative costs of production were substantially higher for a plant below 10% of market share.

In summary, more than 90% of the firms that had entered the industry had disappeared, either through bankruptcy or, in a few cases, through merger. Only a few early, innovative entrants had survived.

The Automobile

More than 100 firms entered and participated in the American automobile industry for a period of five years or longer. Figure 2 illustrates the wave of entry that began in 1894 and continued through 1950, followed by a wave of exits beginning in 1923 and peaking only a few years later, although it has continued until the present day.

As hypothesized, entry began rather slowly, but then accelerated rapidly after 1900, reaching a peak of 75 participants in 1923. In the next two years, twenty-three firms, nearly a third of the industry, left or merged, and by 1930, thirty-five firms had exited. During the ensuing depression, twenty more firms left. There was a brief flurry of entries and then exits immediately following World War II, but as Figure 2 shows, the number of U. S. firms in the industry has been basically stable since 1940.

The number, and scope, of major product innovations is reflected in this pattern of entries and exits. 1923, the year with the largest number of firms, was the year that Dodge introduced the all-steel, closed body automobile. The large number of exits over the next few years corresponds to the fact that by 1925, 50% of the United States production was closed, steel body cars, and by 1926, 80% of all automobiles were of this type. The post-World War II stability in market shares and number of firms reflects the fact that approximately three-quarters of the major product innovations occurred before the start of the War.

New concepts in product accessories and styling were tested in the low volume, high profit luxury automobile. Conversely, incremental innovations were more commonly introduced in lower priced, high volume product lines. General Motors appears to have led in both types of innovations, particularly for major product changes. In certain years, engines show a higher annual magnitude of changes; these changes, however, occur with less frequency than do those in chassis characteristics; body plants are more flexible and continuously changing than are engine plants, which tend to change occasionally in an integrated and systematic way.

From 1894 to 1918, 60 firms entered and none exited. However, we do not have data on innovations for this period. From 1919 to 1929, 22 firms entered and 43 left; during this period, 14 of 32 major product changes occurred, nearly half of the total. From 1930 to 1941, 6 firms entered and 29 exited, and 11 major innovations occurred. Finally, from 1946 to 1962, 4 firms entered and 8 left, but only 7 major innovations were introduced. One can see a continual decline in major product innovations over these two periods (Fabris 1966, p. 85-93).

The Japanese Auto Industry.- Despite an early but unsuccessful attempt by Tokyo Automobile Manufacturing in 1907, Japanese auto production only starts with the entry of Tokyo Gas & Electric Industries (TGE) in 1916--more than twenty years after American auto production started. Contrary to the U.S. pattern, Japan never experienced rapid entry of firms in the industry. Figure 3 shows the flatness of Japan's curve for the total number of firms in the industry, and the relatively few entries occurring during a fifty-year period. Indeed, the total number of Japanese auto producers rises slowly and almost steadily throughout the period 1916-1966, to reach the level of 11 active firms in 1966. This number of participants remains unchanged up to the present, but a period of consolidation appears to be starting today.

During the period 1916-1930 several firms entered the industry, but many of them could not survive as independent entities. There was a strong merger activity in that period: four of the five firms active in 1926 (TGE among them) had merged in 1937 to form the Tokyo Automobile Industry, later renamed Isuzu Motors. Nissan and Toyota, the two firms that were to dominate Japanese production, entered the industry in 1933. Helped several times by government intervention, both before and after the war, the two leading firms were able to weather the tough 1940s and conquer a significant share of the Japanese market. In 1955, Nissan and Toyota had each more than 30% market share in the small cars category (Cusumano 1985). In spite of Nissan and Toyota's market dominance, there was successful entry by new firms after 1950. Daihatsu entered in 1958, and Mazda did it the following year. Honda, which later went on to become a major player, entered the industry in 1963.

Nissan and Toyota, and the other Japanese firms to a lesser extent, put most of their initial effort in mastering the technology and production

process. Nissan, better endowed than Toyota at the beginning, pursued the route of technology transfer agreements with American and European producers. Toyota, lacking the resources to buy technology outside, was forced to employ all its creativity to come up with "in-house" improvements. Both firms succeeded and became major world producers, but Toyota deserves special credit for creating a set of highly efficient production management techniques and tools that have come to be known as the "Toyota production system."

Television and Television Tubes

Research leading to the appearance of television started a couple of decades before the first successful results were achieved. RCA entered the industry in 1929 after Sarnoff, impressed by a demonstration by the inventor Vladimir Zworykin, decided to hire the latter and put him in charge of RCA's Electronic Research Group in Camden. Several other firms or inventors-entrepreneurs entered the infant industry during the 1930s, and all of them contributed to expand the existing frontier of technical knowledge. Philco, Philo Farnsworth, Louis Hazeltine, American Television, and Allen DuMont are some of the most important names.

The commercial birth of the industry can be traced back to the 1939-1940 New York World Fair, where millions of Americans saw television displays for the first time. For the purpose of our analysis, 1939 marks the beginning of the industry. Our data in figure 4 start only in 1949; however, the data clearly shows that the television industry also conforms to our hypothesized relationships. The first decade of the industry (the dotted lines are our

estimates of the real curves' shape for that decade) witnessed a rapid increase in the number of firms. The wave of entry most likely peaks in 1950, the first year of our entry data, or one year earlier. Since 1939, the total number of firms steadily increased until 1952, year in which it peaked at 85 firms. Also, in 1951 the exit wave takes off, to peak a few years latter, around 1956.

Several things happened in the early 1950s in the television industry which had significant impact for the pattern of innovation and competition that was to follow. First, the uncertainty about technical standards for color broadcasting (i.e. UHF versus VHF) was finally resolved by the Supreme Court in 1951. Later, in 1953, the FCC approved the NTSC system, backed by a group of manufacturers headed by RCA. Several firms which had opposed the RCA technical standards dropped out of business because of this legal verdict. Second, several features of the television sets converged to form a dominant design around 1952. The most important dimension of the dominant design was the size of the screen, and therefore the characteristics of the picture tube. The first monochrome set produced by RCA was a 10-inch set. Almost all sets produced in the 1940s had screens smaller than 14 inches. RCA produced its first 21-inch set and other large screen sets around 1952, and they soon became the market standard. Third, during the early 1950s, RCA started to license its television technology to other firms, which further reduced competition and also supports the idea that RCA held rights to most of the key characteristics of the product at that time.

The story of the TV picture and receiving tubes is undoubtedly related to that of the television industry itself. Figure 5 depicts a rapid increase in the total number of tube producers from 1949 to 1956, analogous to that previously discussed for the television industry. In 1956, four years after the peak of the television industry's curve, the total number of firms in the tube

industry reaches its peak at 66 firms. The entry wave also peaks around that time, registering more than 40 entries in the period 1953-1955. The wave of firms exiting the industry takes off slowly during the early 1950s, and reaches a peak in 1958, with 15 firms leaving in that year.

One of RCA's major achievements was the development of the shadow mask color picture tube. The FCC ruled in favor of the RCA compatible color standard on December 17, 1953, and programs were first broadcast in this format in January of 1954. Hazeltine made major contributions to brightness in order to make bright whites. Some problems in manufacture constrained the size of the tubes to 16 inches until CBS laboratories learned how to curve the mask. RCA licensed both of these developments. A problem with the initial tubes was that they were metallic with glass bonded to the front, and this metal envelope proved to be troublesome. On May 8, 1958, RCA publicly announced the first all-glass 21 inch color picture tube, the innovation which was to become the dominant design and which corresponds to the peak in industry participation and the rise in exits as noted above. (We are grateful to John Rydz, a participant in the early RCA developments for the information given here).

The Transistor

Three firms dominated the receiving tube business in the United States in 1950: General Electric, Philco Ford and RCA. Over the ensuing decade, these firms spent more on R&D and received more patents than did new firms entering the industry (counting the expenditures and patents of the Bell Laboratories), but the new firms gained nearly two-thirds of the market. By 1966, three of the new firms--Texas Instruments, Motorola, and Fairchild

Semiconductor--together accounted for 42% of the market, while the vacuum tube manufacturers' share of the transistor market had declined to just slightly more than one-quarter of the total. The difference between established and new entrants in the business would be even more dramatic if one included the IBM's production for its own use. (It is believed to have entered production in 1961.)

Figure 7 shows that the wave of entry, beginning with the announcement of the invention of the transistor in 1948, peaks in 1962, the year after the production of the first silicon integrated circuit by Texas Instruments--two transistors on a single chip--and its rapid establishment as the dominant design. A wave of exits, beginning in the late '50's and early '60's, is shown reaching its peak shortly after this development. 1963 and 1964 saw the development of epitaxial growth and epitaxial reactors for producing integrated circuits and the development of process integration. We will discuss integrated circuits in more detail below as a separate case.

The Integrated Circuit³

The integrated circuit industry is the only one in our sample that does not clearly conform to our hypotheses. In fact, figure 7, displaying only data on U.S. firms, shows no clear peak in the number of firms in the industry during our data period. Therese Flaherty, who is currently studying the integrated circuit industry, suggests that no one product of any generation can be easily considered a dominant design. The integrated circuit has kept on

³ We would like to thank Prof. Therese Flaherty of the Harvard Business School for providing us with access to Dataquest's data for the integrated circuit industry, as well as for her helpful comments and insights about the industry dynamics.

changing substantially from generation to generation, which may explain the very broad plateau we observe in total industry participation with continuing underlying entries and exits.

There are several generations of integrated circuits. For instance, DRAM, the most important segment of the IC industry, has had seven generations up to the present time (1K, 4K, 16K, 64K, 256K, 1MB, 4MB). Competition has been tough both within and between generations. No one firm has been able to maintain a leadership position from one generation to another. In general, American firms have been losing ground to Japanese entrants. The first two generations were dominated by American firms; however, starting with the 16K generation, Japanese firms take a significant share of the market. The industry has grown very rapidly over time; the first generation (1K) had a maximum annual revenue of 152 million in 1977, while the 256K generation--the last one for which revenue data is available--reached annual revenues of 1,807 million in 1987. This growth happened in a fifteen-year time span.

Despite the fact that a quick look at the IC industry suggests that our model has limited explanatory power here, we would like to point out to several issues that cast shadow on such first-sight conclusion. To begin with, most of the entries occur during the early years of the industry. This is especially true for American firms, as it can be seen in figure 7, but it is also true, to a lesser extent, for Japanese or "foreign" firms, as figure 8 illustrates.⁴ Moreover, "enter early" seems to be a winning strategy within each generation, as Flaherty has pointed out. Secondly, the production capacity of dominant firms has been increasing--relative to total market demand--

⁴ Non-U.S. firms are not only, but mostly, Japanese in our data.

throughout the generations. The trend is that fewer companies are increasingly able to satisfy most of the demand. Our model hypothesizes a similar increase in industry concentration. Indeed, it should be noted that exits of American firms from the industry take off in 1985, increasing steadily for the next two years. As American entries are nil during this period, the total number of American firms declines in 1987 to one of its lowest levels. Higher concentration and larger firms is the prevailing pattern in the industry today. Finally, although product innovation is still important in later IC generations, process innovation and production capabilities are increasingly critical as generations pass and greater production volumes are required of participant firms. Such production capabilities form an effective barrier to entry in the industry.

Figure 9 contains data on American and foreign firms pulled together. The curve shows a familiar shape, with the number of firms in the industry increasing steadily up to 1984, and declining thereafter. During the period 1974-1984, there is a rather stable inflow of entrants, first fueled by American firms and later on by Japanese. Exits peak after 1984, with 8 firms leaving the industry during the period 1985-1987. While there seem to be markedly different patterns between U. S. and Japanese entrants in older industries such as the automobile, these data and those on the calculator reported below clearly imply that to analyze technology and competition in more recently formed industries we must do so on a global basis.

The Electronic Calculator

The American calculator industry in the early 1960's consisted of five major companies manufacturing electro- mechanical machines that

controlled nearly 90% of the market--Frieden Monroe, Marchant, Victor, and Olivetti. Frieden, Marchant and Monroe each had approximately 20% of the market, Victor, a slightly smaller share, and Olivetti 10 to 15%. These companies were almost completely vertically integrated due to of the need for a high degree of precision in the manufacture of many specialized parts. There were strong barriers to entry to new firms. By concentrating on specific segments of the market, the major companies avoided intense competition. They also had reinforced their market dominance by setting up extensive distribution and service networks. In addition, through nearly a century of continuing modification and perfection, the technology of electro-mechanical calculators had reached its highest potential; thus, it was not easy for anyone to come up with a dramatic breakthrough that would threaten the status quo.

This situation did not change initially when the electronic calculator entered the market in 1962: The first electronic machines were extremely complex and expensive, and aimed at specialized scientific and technical market segments. Figure 10 shows that between 1962-1970, eleven firms entered the industry, with ten of them surviving. The wave of entry peaked in 1972 with the entry of twenty-one firms in a three-year period, as shown in Figure 10. This was followed by an equally sharp rise in exits in 1974 due to the introduction of the dominant design of the calculator on a chip. The entry of semiconductor manufacturers, such as Texas Instruments and Rockwell in 1972, and National Semiconductor in 1973, further precipitated the departure of firms who were largely assemblers of purchased components. The industry's structure then appears to stabilize, with even a few of the semiconductor makers, such as Rockwell, dropping out, and a small number of the remaining vertically integrated companies dominating the market. Thus, the appearance of a dominant design, and the drive toward vertical

integration which normally follows its appearance, were almost concurrent in this highly compressed example.

Figure 11 superimposes the curves for entries and exits and total of Japanese calculator producers on the curves already plotted for the United States. It is fascinating to note that though the Japanese entered the industry just after the first U. S. entrant, the total number of participants in the industry peaked at an earlier point, and at a somewhat lower level, than was true of the United States. Majumdar interprets the United States pattern as a response to the entry and strong competition from Japanese firms. This seems to be an exceptional case, with the pattern seen before for integrated circuits the more typical one.

Supercomputers

Supercomputers, i.e. the most powerful computational systems at any given time, today achieve speeds in the 100 MFLOPS (Million Floating Point Operations per Second) range. Three major technologies have been used to build supercomputers: sequential, vector, and parallel processing. Sequential computers, whose architecture is often referred as to von Neumann, have only one central processing unit (CPU); they do one thing at a time. Vector processors allow simultaneous computation for some problems, such as problems with vector-like or matrix-like structure. Parallel processing, or more specifically massively parallel processing, is a computer architecture where hundred or thousands of processors are put on the job simultaneously to get the job done faster than more traditional supercomputers and with greater generality.

Traditional supercomputer makers--such as Cray, Fujitsu, Hitachi, IBM, and NEC--produce mostly von Neumann machines with some having vector processors to boost performance. IBM and Univac are considered the first entrants into the supercomputer industry. Cray Research entered in 1972 to become the presently dominant player in sequential supercomputers. A second set of firms, minisupercomputer makers, use the von Neumann architecture with the associated incremental innovations of pipelining and vector processing, but build less powerful machines which target low-end applications with price-sensitive customers. Massively parallel computer (MPC) makers are the latest entrants in the supercomputer industry. Firms such as Thinking Machines, Intel, Floating Point Systems, and Meiko started production around 1985, while the MPC "pioneers" Ametek, Myrias, and Goodyear Aerospace entered the industry only as far back as 1983.

There are two issues of interest in the supercomputer industry at the light of our hypotheses. First, at a more aggregate level, we suggest that the massively parallel architecture will become the dominant design in supercomputers. Therefore, it is likely that we see some exit of traditional firms from the industry in the future, and large players such as IBM or Cray turning to the MPC architecture. Second, although numerous MPC designs exist today, we forecast that some variation of the hypercube configuration will prevail. Further details about these technical alternatives can be found in Afuah and Utterback 1990.

Figure 12 shows the pattern of entry and exit in the massively parallel computer industry segment. Presently, this segment exhibits most of the characteristics of an early, fluid industry life cycle stage. Only time will tell if the industry conforms to our hypotheses.

Summary of U.S. Data

In general, each of the eight industries studied here present a similar pattern of firms entry and exit. American firms, usually small entrepreneurial firms, enter at the dawn of a new industry at a moderate pace. Later, a rapid wave of entry occurs, raising the slope of the curve of total number of firms in an industry. This can be seen in figure 13, which plots such curves for the different industries in this study. After a dominant design is established, the total number of firms declines steadily until it reaches a point of stability—a few large firms remaining in the industry supply most of the demand. Successful firms often enter the industry early.

Our sample includes both large and relatively small industries. In terms of total revenue, automobile and television are the largest industries. It is interesting to note that the peak in number of firms in these two industries occurs at a higher level than all other industries. Larger industries seem to attract more firms. The smallest industry in terms of revenue, MPC Supercomputers, shows the smallest number of firms at its peak. Also, the sample contains industries with both long and compressed periods of competitive turbulence. Purely mechanical typewriters exist for nearly 70 years before the electronic typewriter appears in the market. In contrast, transistors, integrated circuits, and supercomputers are cases in which the competitive turbulence we have observed appears to have occurred in a shorter period of time, though the latter two industries have yet to reach a state of few participants with stable market shares.

Summary of Japanese Data

The sparse data that we have been able to obtain on Japanese entrants in autos, televisions, and integrated circuits, shown in summary form in Figure 14, appear to support the hypothesis that Japanese firms tend to enter an industry later, after the dominant design is apparent. They tend to generally be larger than U. S. entrants including few if any entrepreneurial start-ups, and they seem to hold more tenaciously to market share as seen by a remarkably small number of exits from any of the sectors examined. An exceptional case is the electronic calculator in which the first Japanese entry was just one year later than the first U. S. firm and in which Japanese participation peaked earlier.

Although these instances of successful late entry by Japanese firms may seem contradictory to some of the postulates of our model, we believe that the point requires further thought and study. On the one hand, Japan's late entry in the cases studied has been the result of the technical superiority of the U.S., particularly in product innovation. The gap between the two countries is certainly closing, if not closed at all by now, which may have important implications for the pattern of Japanese entry into new industries. Already in the most contemporary examples in our study, Japanese firms enter the industry right behind U.S. firms, which was not the case in older industries as automobiles where the entry gap was more than a decade. On the other hand, Japanese late entrants seem to focus in what our model predicts is important in a post-dominant-design industry: production process innovations and continuous incremental improvements in both product and process. The Japanese have a single word, *kaisen*, to describe this focus of action. By putting the best of their efforts and resources in achieving

manufacturing excellence, both in terms of production technology and management techniques, they show that it is possible to succeed as late entrant, albeit through massive commitment and persistence.

Thus, the scanty evidence for all but the calculator firms would appear to support the now well-accepted idea that U. S. firms make early gains through stress on novel products during the architectural phase of an industry's development, while Japanese firms make later gains through excellence in manufacturing process, focus and continuous improvement, the issues which appear to be crucial for success during the period of an industry's major growth and stability.

Industry Structure Related to Product Technology

The previous examples have illustrated how the entry and exit of firms from an industry parallels product innovation within that industry. In the fluid state, while product requirements are still ambiguous, there will be a rapid entry of firms with few, if any, failures. As the industry enters the transitional state, and product requirements become more defined, fewer firms will enter and a larger number will either merge or fail. Finally, as the industry enters the specific state, there will only be a few, large firms, each controlling a fairly constant share of the market, with possibly a few small firms serving highly specialized segments.

The earlier Abernathy and Utterback work implies that it is theoretically possible for a firm to enter a product market segment at any of these stages simply by stressing different capabilities and using different strategies. For example, a new entrant in the fluid state might succeed by stressing a high degree of product innovation. An entrant in the transition

state as they define it might succeed by stressing process innovation and process integration. Finally, a new entrant in the specific state might succeed by having financial strength and investing in a plant at the most economic scale and location.

Most of the examples provided here point to the conclusion that entering early is the most viable strategy for an American firm. Entering at later stages, although theoretically possible, has proved to be a much riskier strategy less likely to succeed. However, the successful late entry of large and highly integrated Japanese firms in some of our examples suggests that late entry, although difficult, is possible. If the Abernathy and Utterback concept is correct, then to succeed, late entrants must necessarily follow a consistent strategy, i.e. focus on mastering their production capabilities. But the issue of late entry by Japanese firms, as we suggested above, could bear much further study. Early entry may still prove to be the strategy of choice in the future even for Japanese firms, now that their research capabilities are world class, and American firms are also awakening to the need for constant attention to excellence in manufacturing.

Early entry is an strategy more likely to succeed because in the fluid state, either product or process innovation might be readily imitated; thus, each firm has a relatively equal chance of expanding into the market and developing a dominant design. However, in the transition state, it is clearly the firm with a larger market share which benefits from any process innovation. Similarly, entry with a large plant in the specific state would require enormous amounts of capital as well as a supreme marketing and production organization effort.

Clearly, it is each wave of radical product change that brings with it the entry of new firms--either small, technology-based enterprises or large firms

carrying their technical skills into the new product and market area--and it is these firms which later dominate the restructured industry. For example, carbon filament incandescent lamps replaced gas lighting; they themselves were replaced by metal filament incandescent and later by fluorescent lighting. The Edison Company and the Swan Lamp Company were the innovators in carbon filament lamps, but only an insurmountable patent position allowed Edison to overcome new firms which adopted metal filaments earlier than it did. Sylvania in the United States was the first to innovate with fluorescent lighting. It multiplied its market share by four-fold at General Electric's expense.

Harvested, naturally formed ice for refrigeration was replaced by machine-made ice and later by mechanical refrigeration; it was not the ice harvesting companies which innovated in mechanical means of ice production, nor was it the companies producing ice and ice boxes which innovated in the area of electro-mechanical refrigeration. Finally, in the 20 years from 1889 to 1909, Eastman-Kodak's share of the U.S. photographic market went from 16% to 43% at the expense of much larger competitors, because of its innovation of celluloid roll film, while its competitors continuously improved glass plate photographic techniques.

An elegant recent study, Henderson and Clark (1990) provide substantial support for these observations. They have examined the product technologies and market shares of all participants in the semiconductor photolithographic alignment market through five generations of product technology. Each product generation is dominated by a different company. Moreover, even though changes in technology are seemingly small, akin to the purely mechanical versus electric typewriter case, the observed rapid declines in market shares of the previously dominant firms are the same.

Henderson and Clark are the first to directly, comprehensively and convincingly test this hypothesis.

Supplier Relationships, Vertical Integration and Competitiveness

As a productive unit develops, it typically seeks an increasing degree of control over the value chain. Sometimes, the unit relies more and more on outside sources for production process equipment and components. Firms in the auto industry, for example, developed an early and increasing reliance on suppliers for many types of equipment and innovations. At other times, vertical integration is the unit's choice; uncertainty over component supply is reduced through direct ownership of all the stages of the chain.

Development of relationships with suppliers, and of a more or less captive set of suppliers, appears to be a hallmark of all the evolving product market segments cited. George Eastman was helped greatly by the availability of high quality papers and chemicals, some of which had been developed for the earlier dry plate photographic market; he was also assisted by a burgeoning set of firms manufacturing cameras, a number of whom were subcontracted by Kodak to manufacture camera backs, and later shutters to his design. Similarly, the large number of companies assembling electronic calculators were greatly aided by the availability of high quality components with declining prices from semiconductor manufacturers.

However, in both examples, strengths eventually became weaknesses. Established competitors tried to bankrupt Kodak by capturing the two or three sources of high quality photographic paper, thus drying up his supply. Then, unexplained quality variations in the cellulose that he purchased combined with other variations in chemistry to make several months production of

film useless. Finally, financial weakness and instability among the various firms manufacturing cameras threatened to make it difficult and expensive for Kodak to provide cameras to customers. These events pushed Eastman first in the direction of producing its own photographic paper, then its own chemicals, and finally its own cameras, camera backs and shutters.

Advantages also turned to disadvantages in the calculator industry when rapid reductions in the price of semiconductors left firms that were purely assemblers with enormous inventory losses. As the capability of semiconductor manufacturers mounted and production costs dropped further, virtually all the value added in the calculator occurred in the manufacture of its components; these firms simply integrated forward to provide the entire calculator for the end user.

These examples support Abernathy's hypothesis regarding the relationship between vertical integration and product innovation. Abernathy claims that, "The degree of vertical integration is not static as long as major product changes are taking place. It is rather the equilibrium condition of a continuous effort to extend integration backward in the face of the constant erosion caused by product change. As the technology of product design advances so that novel changes [are] made less necessary, vertical integration can be maintained without such continuous effort."

But suppliers may also become a stable competitive asset for a firm. Japanese firms, and increasingly some American ones, seem to have achieved closer and more cooperative relationships with their suppliers. Indeed, the level of cooperation between many Japanese firms and their suppliers is so high, that often times technical teams from the parent firm work at a supplier's site for extended periods of time, solving a specific production problem. Suppliers are often invited by the parent company to participate in

the design of new products since the outset (MIT Commission on Productivity, 1989). Thus, suppliers may play a highly creative role if the parent firm is able to generate enough loyalty and cooperation. Indeed, such a close relationship suggests that we should probably re-think our very concept of a firm and its boundaries. Only when relationships with suppliers are not cooperative enough, there will be a drive among producing firms to capture those elements of supply which create the greatest uncertainties for them.

However, it should be pointed out that the most innovative producers always provide some of their own production equipment. Abernathy and Fabris show that General Motors and, especially, Ford have made continuing process innovations. In the semiconductor industry, Texas Instruments, in particular, had stressed production process innovation and integration and Tilton's data show a pronounced shift toward process innovation on the part of new firms as the industry developed and as their market shares expanded.

In summary, those firms that survive the introduction of a dominant design appear to be those which shift their emphasis from product to process innovation. These are often firms which seem to vertically integrate or establish the closest supplier relationships--i.e. those which achieve a tight control over the value chain.

Summary

Bearing in mind that the data review here apply essentially to U.S. firms producing assembled products, the appearance of a dominant design does indeed seem to shift emphasis in an industry from predominantly entrepreneurial product innovation toward process development, scale of production, production management techniques, elaborate research programs

aimed at planned incremental change, and correspondingly to advantages for larger firms. The dominant design which emerges is not necessarily the result solely of technical potentials, but also of timing and other circumstances. Once a degree of standardization is accepted, however, major innovations from within an industry seem less and less likely to occur short of a wave of new entrants and increasing competition.

Strategies for entry, development, and resource allocation should we believe bear a relationship to the current state of the technical development of an industry's product and process, as well as the degree to which these are integrated. Counter strategies are likely to be highly risky, and thus should be thought out with great care. While the process described is not necessarily irreversible, the evidence to date indicates that it is highly directional. Surviving to become a dominant firm is an improbable event (the outcome for only 5-10% of U.S. entrants in the cases examined) doubtless requiring superb execution of product design, process development and organization, and timing in what is at least initially a highly uncertain environment.

Failures of firms in our analysis seem to be a matter of weakness of technical resources or slowness in development, not simply of lack of scale or market power. Thus, mergers of weaker firms are most often seen in the cases above to be followed by failure. Few of the mergers noted during the waves of exit shown above appear to be truly complementary ones which extend product lines and markets. Normally in the cases studied, mergers which occur after a dominant design appears quickly fail. The pattern shown by the emerging dominant firms appears to be one of growing internal technological and manufacturing strength rather than one of successive mergers with competitors. Development of close and technically creative supplier relationships appears to be a key to successful, continuing

dominance in many cases. There is also the potential that such closed relationships may result in even more rigidity and resistance to change by entrenched firms.

Questions for Further Research

There is suggestive evidence both in the literature and in the cases examined that product performance and cost are strongly dependent on entry, exit and growth of competing firms. In particular, performance improvement seems to reach a maximum as firms pour into an industry during its formative or architectural period, prior to the dominant design. Klein has shown this to be true in the case of autos and aircraft engines. Modis and Debecker (1988) clearly demonstrate that periods of greatest improvement in the performance of microcomputers correspond to waves of newly entering firms. Conversely, cost reduction may reach a maximum as firms struggle for dominance during the time of most rapid exit from an industry. The peak period of exits is a period of rapid revenue growth both for the industry as a whole, and especially for the emerging dominant firms as they increase their scale of operations. These are important questions bearing centrally on issues of technology strategy. They may be well worth the effort needed to gather data in greater detail on firm's market shares, product performance and costs where possible.

The summary curves of industry participation in Figure 14 show striking differences in the total numbers of firms entering different industries. Does the total number of firms vary with the size of the market for each product? It seems reasonable that the total markets for autos,

televisions and tubes, and typewriters are larger than those at any corresponding point in development for calculators or supercomputers.

Does a rather flat summit or plateau in total industry participation as is the case for typewriters and integrated circuits reflect either continuing technological change in a product or many rapidly succeeding generations? Conversely, does the sharpness of a peak in total industry participation reflect strong economies of scale as in autos and calculators and complementary assets such as software written or a particular architecture as in the case of supercomputers? Can we infer the occurrence of a dominant design from the occurrence of a peak in participation and the beginnings of consolidation in an industry? This certainly seems to be the case for massively parallel supercomputers, as Afuah and Utterback (1990) have predicted.

Late entry has not seemed to be a viable strategy for U.S. firms. However, late entry and tenaciousness seem to be the common strategy for Japanese entrants in the cases studied. Are highly integrated Japanese firms better able to absorb the heavy investments and learning that such a strategy implies and to remain prosperous survivors than U.S. firms? Some observers have pointed to the fact that all major Japanese semiconductor producers support consumer electronics or computer production as an explanation for their apparent ability to survive low levels of profitability and return. In other words, businesses are judged as strategic assets contributing within a larger complex, rather than as independent business entities. Some of the implications of our work here for organization structure on a macro-scale seem to be well worth further examination. Also with respect to Japan, it remains to be seen whether Japanese firms will continue entering late now that their research capabilities are becoming comparable with those of American firms.

Finally, we have not examined cases of highly capital intensive, process driven industries such as petrochemicals, fibers or glass. We suspect that much different patterns may exist in such cases due to high barriers to entry. For example, with regard to the glass industry the peak in industry participation for plate and flat glass appears to have occurred prior to the introduction of the Float process. The Float process developed by the Pilkingtons led to a rapid wave of exits and consolidation both in the glass industry and in product types. The technological innovator licensed firms such as LOF and PPG, but while the Float process diffused in this manner, there were no new firms formed to enter the business. The Float process created a major step in economic plant scale at the same time.

If our conclusions are correct when more generally examined and tested, then any action based on a static analysis of a firm's strengths and strategy will probably reduce that firm's chances for long run survival, much as highly specialized animals fail to survive slight shifts in climate and habitat while generalized foragers prosper. This is the more strikingly clear if a firm has as its ambition surviving a generational shift in technology. Most firms fail to survive, at least as players in a particular product arena, even in the competitive shake out seeming precipitated by the synthesis of a dominant product design. The number able to survive a generational shift is apparently vanishingly small. The patterns observed here clearly imply that a firm should suboptimize in the short term in order to build the flexibility, skills, and resources it will almost surely need if it is to become a dominant survivor.

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