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Patterns of Industrial Evolution, Dominant Designs, and Firms' Survival

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ABSTRACT

This paper surveys recent research on the concept of a dominant product design. The point of departure for the survey is the idea that dominant designs occur which shift the terms of competition in an industry. A dominant design is defined as a specific path along a design hierarchy, which establishes primacy among competing design paths. The way in which this might occur and its implications for innovation and competition are then explored. Evidence from the literature covering a number of industries in the United States is then surveyed and compared with original evidence, first presented here, from some of the same industries in Japan. The dominant design which emerges in each industry is not necessarily the result solely of technical potentials, but also of timing, collateral assets, and other circumstances. In several cases dominant designs have not or have not yet occurred. Once a degree of standardization is accepted, major innovations in an industry seem less and less likely to occur short of a wave of new entrants and increasing competition. In contrast, entry and innovation in Japan seem to occur following appearance of the dominant design, and implies that firms can pursue widely different strategies so long as their strategy is linked to the state of evolution of their core technology. Implications for further research are discussed, and the idea that a dominant design is related to information economies for users is introduced. Thus, for a design to be dominant or a standard requires a degree of experimentation and a rich collaboration between producers and users, not simply a synthesis of parts and functions in a product.

Schumpeter considered innovation both the creator and destroyer of corporations and entire industries. Cristiano Antonelli, Pascal Petit and Gabriel Tahar (1992) note that in his early works Schumpeter (1912) insisted on the role of entrepreneurs in seizing discontinuous opportunities to innovate. This initial approach they continue, stressed the discontinuities of the innovation process. In later years Schumpeter (1942) began to place greater stress on the role of larger enterprises in innovation, seeming to believe that as scientific knowledge accumulated there was a threshold investment in R & D below which a firm could not be an effective player. The writers have always been troubled by this conflict in Schumpeter's views. The present analysis suggests that the former hypothesis is true for areas of emerging product technology and firms involved in product innovation, especially for assembled products, that is for what Abernathy and Utterback (1975 and 1978) termed discontinuous and fluid phases, while the latter hypothesis might well hold for process innovation and for many non-assembled products, and for firms producing standard products and large systems (which the above mentioned authors termed the specific phase).

In earlier work Utterback and Abernathy (1975) 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.

We believe that a firm's probability of surviving through time will be directly affected by a firm's entry timing *vis a vis* the evolution of technology in the industry (Suarez and Utterback 1993). In particular, we hypothesize that the probability of survival will tend to be greater for firms entering the industry before the emergence of a dominant design than for firms entering after it. The period following the dominant design will be marked by a wave of exiting firms made up of both early entrants not able to master all aspects of the technology and those firms unlucky enough to enter following the dominant design as well. The development by incumbents of collateral assets and economies of scale (due to increased production after a dominant design) will represent significant barriers to entry for firms that venture to enter the industry after a dominant design. Moreover, strong patent positions may have been established by earlier entering firms that are difficult for later entrants to completely circumvent.

An alternative hypothesis would be that firms entering *before* a dominant design is established will have lower chances for survival. While firms entering after a dominant design is established face difficulties as late entrants in overcoming entry barriers, firms entering before will face a high chance of choosing the wrong design. Why do we suppose that firms entering during a period of experimentation will do better than those which enter after a commercially successful design has emerged? What are the circumstances under which early entry will be easier, and what are those which might auger against our hypothesis?

In this chapter we intend to explore the questions above by looking at a series of examples arrayed over the past century. These include typewriters, the automobile, television sets and picture tubes, transistors, integrated circuits, calculators disc drives 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.

WHAT IS A DOMINANT DESIGN?

The point of departure for our work is the idea that dominant designs occur which shift the terms of competition in an industry. A dominant design is a specific path, along an industry's design hierarchy, which establishes dominance among competing design paths (Utterback and Suárez 1992. See Figure 1 for an illustration of a design hierarchy). Recall from Clark (1985) that design trajectories and paths are influenced by both technical and market factors. For the purposes of this chapter, we define the occurrence of a dominant design in a given industry based on the knowledge of industry experts. Industry experts were given a rough idea of the general model proposed here and--without seeing our data--they identified a design they considered the dominant one in the industry. They were also asked about the date on which that design was introduced in the market. We further checked the date given against documentary evidence.

FIGURE 1 ABOUT HERE

A dominant design will embody the requirements of many classes of users of a particular product, even though it may not meet the needs of a particular class to quite the same extent as would a customized design. Nor is a dominant design necessarily the one which embodies the most extreme technical performance. A dominant design will, however, represent a milestone or transition point in the life of an industry. Table 1 provides the sources from which we have identified and surmised dates of the dominant designs for each industry considered in this paper.

TABLE 1 ABOUT HERE

Dominant designs often have the result of drastically reducing the number of performance requirements to be met by a product by making many features implicit. Thus, few today would ask if a car had a self starter or whether a typewriter could produce upper and lower case letters, though these were features in pre-dominant design models. 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 television 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 industry structure and competition.

HOW DOES A DOMINANT DESIGN OCCUR?

How does technology evolve so that a given design becomes the dominant one? Prior to the appearance of a dominant design many of its separate features may be tried in varied products which are either custom designed or designed for a particular and demanding market niche. The turbulent competitive process through which many firms enter and some leave an industry may be seen as *a process of experimentation,* with each product introduction viewed as a new experiment on user preference (Klein 1977). This period has been called the fluid period of the industry (Abernathy and Utterback 1978). During this period performance dimensions will tend to be many and highly varied and can often be incommensurate. As a product evolves certain features will be incorporated, subsuming the related performance dimensions into the design. With the appearance of the dominant design the product can be described by a few related and measurable dimensions. A dominant design then, is synthesized from more fragmented technological innovations introduced independently in prior products and tested and often modified by users of those prior products. Following the appearance of a dominant design the industry enters the more orderly period characterized by a few large competitors and stable market shares that Abernathy and Utterback termed the specific period or phase.

A few examples may help clarify this idea. Early versions of the typewriter were able to produce only capital letters. The addition of lower case letters and a shift key was at first a specialized feature. Numbers and tabulation were similarly derived. The earliest typewriters marked on a paper held inside the machine. "Visible typing," with the paper in view of the operator, similarly began as an attraction of just a few models. These features were later synthesized in the Underwood Model 5, which was to become the exemplar of the dominant typewriter design in 1906. Who today could imagine typing without seeing the text, easily shifting to capital letters, or easily entering numbers and aligning columns? These are no longer serious issues or advertised as advantages of one or another manufacturer's product. They are subsumed within the dominant design established by Underwood. (The typewriter industry will be discussed in more detail below.) Yet within recent memory the Apple II personal computer produced only 40 columns of capital letters. The ability to use 80 columns, to type in upper and lower case or to add a numeric keypad were all features to be purchased from different vendors and installed by the proud owner! Users of even large computer systems patiently embedded control characters in the text of various editing and word processing programs until the innovation of the WYSIWYG (what you see is what you get) display at Xerox PARC (Palo Alto Research Center), later adopted in the Apple Macintosh, allowed users to easily change type styles and sizes in a fascinating analogy with visible typing.

The process of experimentation that leads to the emergence of a dominant design is not only a technological process. In fact, the emergence of a dominant design is the result of a fortunate combination of technological, economic, organizational, and inter-organizational factors. The process of experimentation described above is overall a learning process. In reality, there is technological, market, and organizational learning involved. Commenting on one of our previous papers, Langlois writes, "the firm must not only learn about what will work technologically but also about what consumers want." Thus, factors other than technology also come into play. We have identified several non-technology factors that have a critical effect on the emergence of a dominant design:

- possession of collateral assets

- industry regulation and government intervention
- strategic maneuvering at the firm level
- existence of bandwagon effects or network externalities in the industry
- management of the user-producer connection.

Collateral assets (Teece 1986) have a reinforcing-loop relationship with dominant designs. These assets may help a firm to impose its design as the dominant one and, in turn, the possession of a dominant product often helps a firm accumulate collateral assets at a higher pace than before (Suárez and Utterback 1992). Industry regulation (and other forms of government intervention, such as large purchases) have the power to literally enforce a given design as the dominant one, as with the RCA TV broadcast standard. The strategy followed by the competing firms may also help determine the dominant design, as shown by research on the VCR industry (Cusumano, Mylonadis, and Rosenbloom 1991). The existence of a bandwagon effect or network externalities[1] in an industry often prompts and accelerates the emergence of a dominant design. In cases like this, firms which are able to achieve larger scale more quickly than their competitors may have a better chance of winning the race to settle the dominant product.

Finally, the way each firm manages its user interface may have a significant effect on a firm's ability to impose a dominant design. We said above that a dominant design is partly the result of market learning. Therefore, close contact with users during the early period of experimentation will help firms determine which product features consumers look for, so that they can include those features in their designs. Managing the user interface in the search for a dominant design may take the form of especially close relationships with "lead users" (von Hippel 1988), close interaction with users' associations or interest groups, etc.

HYPOTHESES

The Period Around the Dominant Design

We suggest that the emergence of a dominant design (via the creative synthesis of a new product innovation or the effect of some of the factors described above) results in a temporary monopoly situation, high unit profit margins and prices, and sales of the dominant design in those few market niches where it possesses the greatest performance advantage over other competing alternatives. This is in line with Schumpeter's pathbreaking "creative destruction" model and subsequent studies on the economics of innovation (Schumpeter 1939, Freeman 1986). As volume of production and demand grows, and as a wider variety of applications is opened for the innovation, many new firms will 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. It is common to think of new, innovative entrants as being small firms. We do not agree entirely with the idea that only small firms can be innovative in a young industry. 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).

The appearance of a dominant design shifts the competitive emphasis to favor those firms, large or small, which are able to achieve greater skills in process innovation and process integration, and with more highly developed internal technical and engineering skills. We hypothesize that the peak of the total population curve for any industry manufacturing assembled products in the United States will occur around the year in which a dominant design emerges in that industry.[2] A dominant design has the effect of enforcing standardization so that production economies can be sought. Effective competition can then take place on the basis of cost as well as product performance (Utterback and Abernathy 1975). The emergence of a dominant design will mark the beginning of a shake-out period in an industry (as we will see in the data presented below). Firms that are not able to make the transition toward greater product standardization and process innovation will be unable to compete effectively and will eventually fail. Others may possess special resources and thus successfully merge with the ultimately dominant firms. Some weaker firms may merge and still fail. Overall, a firm's inability to change its organization structure and practices along with the evolution of technology in the industry will be a major source of failure.

The Post-Dominant Design Period

Eventually, the market reaches a point of stability in which there are only a few large firms having standardized or slightly differentiated products and relatively stable sales and market shares, until a major technological discontinuity occurs and starts a new cycle again.[3] During the period of stability, 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.

It is only after a dominant design is established that economies of scale can come in to play with powerful effect, leading to rapid growth of those firms which most competently master the development of products based on the dominant design, to the detriment of those firms which are slower to adapt. Prior to the appearance of a dominant design economies of scale will have little effect, because a large number of variants of a product will be produced by the many competing entrants in an industry with each producing at relatively small scale. Thus, we propose that economies of scale are of primary importance after a dominant design is in place. In other words, traditional economic assumptions about economies of scale are much more appropriate to the period following a dominant design than to the period of experimentation and creative turbulence which precedes it.[4]

A hallmark of stability is a concerted drive among the surviving firms toward tightening their control over the value chain. This process can take one or both of the following forms: (1) an improvement in 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.

Earlier versions of the model presented here (e.g. Abernathy and Utterback 1978) considered vertical integration during the period of stability as an inevitable outcome of technological evolution in an industry. Here, we claim that what surviving firms really seek is "control over the value chain." Vertical integration is but one possibility to achieve such control. Today firms are increasingly relying on improved supplier and distributor relationships to achieve control over the value chain (Piore and Sabel 1984, Florida and Kenney 1989, Aoki 1984). The emergence of a set of more or less captive suppliers of equipment and components linked to a large firm is commonplace. Although closer relationships with distributors may have similar benefits, most of the literature has focussed on supplier relationships, particularly on describing the Asian (mostly Japanese) model. Indeed, the level of cooperation achieved by Asian firms and their suppliers is so high, that often technical teams from the parent firm work at a supplier's site for extended periods of time, solving a specific production problem (Cusumano 1985, Amsden 1989). Suppliers are often invited by the parent company to participate in the design of a new product from its outset (Dertouzos, et al. 1989, Clark and Fujimoto 1991).

Suppliers may play a 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 will there be a drive among producing firms to capture those elements of supply which create the greatest uncertainties for them--i.e. a drive toward vertical integration.

Timing of Entry and Dominant Designs

The implications of our framework point to the hypothesis that entering before a dominant design emerges is the most viable strategy for a firm. As Suárez and Utterback (1992) show, the hazard profile (the instantaneous probability of failure) goes up for firms entering after the dominant design. After a dominant design emerges, each year it gets more difficult for new entrants to survive. As the above discussion implies, this is due to the fact that after a design has achieved dominance, firms which master that design will increasingly grow in volume, gain market share, build up collateral assets, exploit economies of scale, and obtain name recognition among customers. All of these points become high barriers that post-dominant design entrants have to overcome if they want to succeed.

Early, pre-dominant design entrants often become the industry leaders. It is each wave of radical, or architectural (Abernathy and Clark 1985) 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. 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 (Utterback 1994).

RELATED RESEARCH SUPPORTING OUR PREDICTIONS

Mueller and Tilton (1969) were among the first to present an hypothesis similar to ours. 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 appear 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, the authors suggest that as the number of firms entering the industry increases and more and more research and development (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.

Some economists interested in technological innovation have proposed models that parallel many of the features of our model. Gort and Klepper (1982) present a five-stage product life cycle model which they then contrast with data on 46 industries. The implications of their model for industry structure over time anticipate ours. Klepper and Graddy (1990) present an analytical model that attempts to capture the main "regularities" discussed in Gort and Klepper 1982. Gort and Konakayama (1982) estimate probabilities of entry and exit based on a logistic model. Although important contributions bridging economics and the management of technology, these studies omit important insights coming from a deeper understanding of an industry's technological evolution. For instance, the data on innovations are not divided between product and process innovation, and thus do not allow the authors to test whether the locus of innovation changes over time. The identification of each stage in prior studies is basically done by looking at the net entry data itself. The work presented here attempts to isolate the identification the different stages from the industry's net entry data by examining the evolution of technology through independent sources. The emergence of a dominant design, for instance, is seen as an unequivocal sign that a new stage has begun.

LIMITATIONS AND CAVEATS

There are several instances in which the propositions put forward in this chapter loose some or all their validity. The idea of a dominant design does not seem to hold in industries producing non-assembled products such as rayon, glass, pulp and paper, metals, or industrial gases. It may be that in such cases a similar coalescence of technology around "enabling processes" may occur such as the Float Glass process or medium consistency pulping (Utterback and Nolet 1978, Anderson and Tushman 1990). Cases such as integrated circuits or photographic film may be difficult to classify, and may share some characteristics of both assembled and non-assembled products.

Because non-assembled products contain a smaller number of different materials than assembled products, there is a more concentrated focus of technological effort and experimentation in the production process, which goes through similar periods of variation and experimentation, resulting in what might be called an enabling technology. This enabling technology incorporates many of the elements needed in a continuous production process and allows the focus of technological effort to shift to process improvement rather than process innovation and design. This means that firms producing non-assembled products may be less vulnerable to imitation and international competition. Indeed, the chemical industry remains one of the strongest exporters in the United States, though other reasons such as its strong science base and relative lack of government participation in research may be more influential factors. Much work remains to be done to begin to understand these striking differences.

Another instance where our model should be viewed with caution is when network externalities exist. For cases in which there are strong network externalities, we do not expect the above arguments to completely apply. Langlois (1991) argues that in the case of the IBM personal computer, for example, the dominance of a standard *increased* entry in the industry, since makers of clones could enter without the investment needed to insure adequate software. For cases in which industry standards may differ from standards set based on technical qualities alone, Langlois further argues that the creation of a standard may open up the possibility of new entry by reducing consumer uncertainty. In our own data the adoption of the RCA broadcast standard for television presents just such a case, and entry does indeed increase rapidly for a brief period after the adoption of that standard.

SUMMARY OF HYPOTHESES

In summary, we propose that most newly created industries will end up crystalizing a dominant design. The dominant design will be the result of a period of technological and market experimentation plus the net effect other factors such as the distribution of collateral assets among the firms, the existing industry regulation or other types of government intervention, the specific strategy followed by each firm, the existence of network externalities in the industry, and the way each firms manages its user interface.

The period preceding the emergence of a dominant design will be marked by a significant net entry of firms into the industry. The total number of firms in the industry will grow to reach a peak at about the time that the dominant design emerges. 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 the total participants reaches a relatively stable condition with a few firms sharing the market. A major technological discontinuity would start a whole new cycle again.

We contend that a firm's probability of success will be higher if it enters the industry before the dominant design. As explained above, the emergence of a dominant design permits a few firms to raise barriers to entry by exploiting economies of scale and accumulating collateral assets. Our proposition regarding entry timing *vis a vis* the evolution of technology extends the findings of the literature on entry timing by explicitly incorporating technology into the analysis.

SUMMARY OF DATA

In general, each of the eight industries studied here presents 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 2, which summarizes 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.

FIGURE 2 ABOUT HERE

A list of the industries with their respective dominant design dates can be found in Table 1. Our sample includes both large and relatively small industries. In terms of total revenue, the automobile and television industries are the largest. 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, massively parallel 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 electric 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.

TABLE 1 ABOUT HERE

THE TYPEWRITER

According to Engler (1969) 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 paper, 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 (data from Engler 1969). Many others which entered and quickly exited, without making any significant penetration, have been left out of the records. Most of the actively competing firms were started between 1886 and 1899, forming the sharp wave of entry hypothesized.

The set of features which was 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 having the page obscured. 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 the 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 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 production costs by improved design.

After Underwood's Model 5 and Hess' innovations, competition centered mainly around features and increasingly on production costs. Figure

3 shows the pattern that our model predicts. The rapid growth in the number of firms halts in 1899, the same year in which 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.

FIGURE 3 ABOUT HERE

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. According to Engler (1969) 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. The data for this industry are presented in graphic form in Utterback (1987 based on data from

Fabris 1966). The wave of entry 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. Again, data for many shorter lived firms or ones which became parts producers or other specialists are not included. As hypothesized, entry began rather slowly, but then accelerated rapidly after 1900, with participation in the industry 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 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 (Abernathy 1978). 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.[5]

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.

Of firms which produced automobiles for five years or more from 1894 to 1918, 60 firms entered and none exited. We do not have data on innovations for this period, but we assume that architectural innovations overwhelmingly predominated. 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 three periods (Fabris 1966, pp. 85-93).

TELEVISION AND TELEVISION TUBES

Research leading to the appearance of television started several 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 Zworykin 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 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's 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 show that the television industry conforms to the hypothesized relationships. The first decade of the industry (the dotted lines are our estimates of the real curves' shape for that decade) obviously 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. The total number of firms steadily increased until 1952, the year in which it peaked at 85 firms. Also, in 1951 the exit wave takes off, to peak around 1956 (Utterback and Suárez 1993).

FIGURE 4 ABOUT HERE

Several things happened in the early 1950s in the television industry which had a significant impact on 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 due to 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 (Utterback and Suárez 1993).

FIGURE 5 ABOUT HERE

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 interface proved to be troublesome. The 21 inch, all-glass picture tube is considered here to be the dominant design. The 21 inch, all-glass tube (first black and white, then color) was by far the biggest seller after the mid-fifties. The first such tube, black and white, was introduced by RCA late in 1955, and captured a significant portion of the TV tube market during the rest of that decade. The advent of reliable color tubes contributed to the difficulties that many tube producers were experiencing during the late fifties and fostered concentration in the industry. Indeed, on May 8, 1958, RCA publicly announced the first all-glass 21 inch color picture tube, which was to hold a large share of the color tube market.[6]

THE TRANSISTOR

According to Tilton (1971), 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 a cohort of new entrants gained nearly two-thirds of the market. By 1966, three of these new entrants--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 6 shows that the total number of firms in the industry starts to rise rapidly with the announcement of the invention of the transistor in 1948. The rapid increase in the total number of firms is virtually halted around 1959, the first year in which the planar transistor was in commercial production. Transistors produced through the planar process rapidly became the dominant design in the industry. First introduced by Fairchild Semiconductors, planar transistors presented many advantages over the older mesa transistor technology. In particular, the planar transistor was flat, which meant that electrical connections could be achieved by depositing an evaporated metal film on appropriate portions of the wafer. This was a great advantage over the mesa transistor, whose irregular surface dictated that electrical connections be done laboriously by hand. The planar transistor prompted a drive for producing low-cost transistors typical of after-dominant-design stages of the industry cycle. Exits in the industry, almost nil before 1959, become commonplace afterwards. The years 1963 and 1964 saw the development of epitaxial growth and epitaxial reactors for producing integrated circuits and further development of process integration. We will discuss integrated circuits in more detail below as a separate case.

FIGURE 6 ABOUT HERE

THE INTEGRATED CIRCUIT[7]

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 the period studied. 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 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 integrated circuit 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 loosing 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 dollars in 1977, while the 256K generation--the last one for which revenue data are available--reached an annual level of 1,807 million dollars in 1987. This growth happened in a fifteen-year time span.

FIGURE 7 ABOUT HERE

Despite the fact that a quick look at the integrated circuit industry suggests that our model has limited explanatory power here, we would like to point out to several issues that cast shadow on such a 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 can be seen in Figure 7, but it is also true, to a lesser extent, for Japanese or "foreign" firms.[8] 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--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 integrated circuit 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, and plant scale and investment costs seem to have steadily increased.

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 a high level. Thus, it was not easy for anyone to come up with a dramatic breakthrough that would threaten the *status quo*. In its early years, true to the hypothesized pattern, this industry too displayed a large number of competitors and a wide variety of designs Martin 1992).

This situation did not change initially when the electronic calculator entered the market in 1962. The first electronic machines were extremely complex and expensive having more than 2300 discrete parts, and were aimed at specialized scientific and technical market segments. Figure 8 shows (with data from Majumdar 1977) 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 the Figure. However, exits begin in 1971, rising sharply during the next few years. 1971 marks the year of the introduction of the dominant design of the calculator on a chip, which made the assembly of units extremely simple--merely piecing together the chip, display device, and keyboard. The entry of semiconductor manufacturers, such as Texas Instruments and Rockwell in 1972, and National Semiconductor in 1973, further precipitated the departure of firms which 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 often follows its appearance, were almost concurrent in this highly compressed example.

FIGURE 8 ABOUT HERE

WINCHESTER DISC DRIVES

Clayton Christensen (1992) argues persuasively that established firms failed to master each successive generation of Winchester disc drive technology through being too wedded to existing customer demands and not attentive enough to the emerging demands of manufacturers of smaller computers. Five generations of Winchester drives are described in Christensen's data: 14 inch drives, 8 inch drives, 5 1/4 inch drives, 3 1/2 inch drives, and 2 1/2 inch drives. In the first two generations the motor was separate, while in the third it was incorporated in the drive spindle. Further important design changes were made in the 3 1/2 inch drives, while the 2 1/2 inch drives are essentially a miniature version of the 3 1/2 inch drives and have not to date enjoyed important sales growth.

Established firms were the real leaders in introducing thin film disc drives, which displaced the own magnetic technologies. Most of the new entrants failed in this discontinuity. (This dovetails nicely with McCormack and Utterbacks' (1993) fiber optics data.) Likewise with the thin film head IBM spent $300 million to develop thin film disc drives, while DEC spent $200 million. On the other hand new entrants were the leaders in introducing new architectures, that is in Henderson and Clarks' (1990) terms assemblies of existing components related in different ways. Conversely, while established firms led the difficult but incremental improvement of components, new firms led with new architectures using established components. The leaders in thin film disc drives were not able to keep that proprietary. This did not affect industry structure or market shares despite its high cost. Leaders in architectural change, despite its being fast and cheap, dethroned the leading companies in the Winchester drive industry.

Why are firms willing to pay hundreds of millions of dollars for incremental changes and not a few millions for a new frame size? Perhaps because the new frame size did not address the *needs of their established customers*. Smaller drives at first were much slower and more expensive, but they did enable a hard drive on the desk top. The data summarized in Figure 9 when examined in detail show that the leaders in each new generation of drives were different from those that headed the list in the prior generation, with the exception of the current 2 1/2 inch drives. Christensen claims that the 3 1/2 inch drives incorporate all the the features and functions that will be seen in 2 1/2 inch and even smaller drives, and thus constitute a dominant design. This is a pleasing conclusion since it perfectly supports our hypothesis as shown by our independent analysis of his data in Figure 9.

FIGURE 9 ABOUT HERE

Today yet another revolution in technology is waiting in the wings in the form of so-called "flash memories." These are credit card sized semiconductor memories that hold as much data as did the early generation Winchester drives without requiring moving parts. They currently cost several times the amount that one would spend for a more capacious disc drives, but they are being designed into lap top computers. Drive makers have countered defensively by introducing modular and interchangeable disc drives, and so history repeats itself.

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 in which hundreds or thousands of processors are put on many jobs simultaneously to get the job done faster than more traditional supercomputers and with greater generality. This however requires wholly new software - a problem of collateral assets.

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, as shown in Figure 10. 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 (data from Afuah and Utterback 1992).

FIGURE 10 ABOUT HERE

There are two issues of interest in the supercomputer industry in 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, Afuah and Utterback (1992) forecast that some variation of the hypercube configuration will prevail, because it seems to be the only easily scaleable design.

COMPARATIVE ANALYSIS

Nearly all these examples point to the hypothesis that entering early is the most viable strategy for a firm. 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.

Bearing in mind that the data reviewed here are derived essentially from 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, collateral assets 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 fortunate 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, or to stem from lack of knowledge of emerging markets, 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 and of knowledge of emerging markets, rather than one of successive mergers with competitors. Development of close and technically creative supplier relationships appear to be keys 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 (Amburgey, Kelly and Burnett, 1993).

There is suggestive evidence both in the literature and in the cases examined to infer that product performance and cost are strongly related to 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 (1977) 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 firms' market shares, product performance and costs where possible.

The summary curves of industry participation in Figure 2 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 (1992) have predicted.

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 seemingly 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 in the longer term (Utterback and Kim, 1983, Gersik, 1991).

COMPARISONS BETWEEN THE UNITED STATES AND JAPAN

The earlier Abernathy and Utterback (1978) work implies that it is *theoretically* possible for a firm to enter a product market segment at any stage simply by stressing different capabilities and using different strategies. For example, a new entrant in the fluid state as they define it might succeed by stressing a high degree of product innovation. An entrant in the transition state 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.

Although entry at any state is theoretically possible, most of the examples provided above point to the conclusion that entering early is the most viable strategy for an American firm. Entering at later stages has proven to be a much riskier strategy, less likely to succeed (Suarez and Utterback 1993). However, the successful entry of large and highly integrated Japanese firms after a dominant design has emerged in some of our examples apparently contradicts our findings. Indeed, post-dominant design entry seems to have been the strategy of choice for most Japanese firms. As Harvey Brooks writes "the typical pattern of Japanese success has been rapid penetration of a narrow, but carefully selected segment of broad, expanding world market in which superiority in production efficiency, economies of scale, and exploitation of learning curve effects were particularly important.......Japan has been able to capture an important share of the market for selected products just behind the current technological frontier."[9]

Figure 11 shows the pattern we describe. In the figure, data for total participation of Japanese firms are shown for the cases of automobiles, television sets, electronic calculators, integrated circuits and Winchester disc drives respectively. The Figure also indicates the date in which a dominant design emerged in the U.S. for each industry considered.

FIGURE 11 ABOUT HERE

For three of the products in question, autos, televisions and integrated circuits the pattern in Japan is completely different than that in the United States shown earlier in this chapter. The number of active firms in Japan shows an slow but constant growth over the entirety of the periods studied. This growth is generally the result of steady, relentless entry with almost no exit of firms from each industry once established. Note also from Figure 11 that in three of four cases, the peak in Japanese entry occurs after the emergence of a dominant design in the U.S.

The two most recent products for which we have data are more similar to the U. S. case than are the earlier three. Both electronic calculators and Winchester drives exhibit a distinct peak, and both are lower than the U. S. peak for the same industry. The Winchester drive peak occurs slightly later than the 1983 peak in the U.S. as expected, but the Japanese peak in the calculator case is actually two or three years earlier than that in the U. S.[10] Note also that, unlike the other three cases, Japanese firms enter the industry in these two cases at about the same time as their U.S. counterparts. Finally, with the sole exception of Winchester drives, there are more Japanese competitors than American at the end of the game, the result not of more Japanese entrants, but rather of much greater frequencies of American firms moving out of the competitive arena, while relatively few Japanese firms ever leave. Japanese entrants tend to be larger firms and conglomerates, which tend to have more collateral assets, and which are more persistent than U. S. firms, many of which will be smaller new entrants.

There are two main issues to highlight when comparing the U.S. and Japanese patterns. First, the successful post-dominant design entry by Japanese firms observed in autos, televisions and integrated circuits can be explained by our theory, and therefore it does not necessarily contradict our earlier findings. Second, there seems to be a tendency for Japanese firms in more contemporary industries (such as Winchester disks and electronic calculators) to enter as early as their American counterparts. This emergent pattern makes us think that our findings for American firms will begin to be replicated by research on contemporary Japanese data.

Successful post-dominant design entry does not contradict the postulates of our theory. If our propositions are correct, then to succeed, post-dominant design entrants must necessarily follow a consistent strategy, i.e. focus on mastering their production capabilities. This seems to be in line with what the Japanese late entrants have done. The Japanese examples in autos, televisions and integrated circuits complement our U.S. data and show that productive units can pursue widely different strategies as long as their strategy is matched to the state of evolution of the technology. With Japan's rising affluence and large current investments in research, technology and plant and equipment, and with the U.S. awakening to the need of manufacturing excellence, one might expect, as does Ohmae (1985), that the pattern in Japan will more and more closely resemble that of the United States as time passes. If this is the case--as our limited data suggests--then predominant design entry may still prove to be the strategy of choice in the future even for Japanese firms. This is an interesting issue which clearly deserves much further study.

DIRECTIONS FOR FURTHER RESEARCH

What are some of the broader questions raised by cases and comparisons presented above? The first issue relates to cases in which our theory apparently does not apply. In particular, What happens when a dominant design seems not to occur? For example, the personal computer market is shared by several seemingly incompatible or partially compatible designs including Apple's MacIntosh, IBM's personal computer, inexpensive work stations made by Sun and others. In this case focussing on the hardware alone may simply lead one astray from recognizing a possible dominant design. According to George White, "the IBM PC is not the key. The key is the Intel 8088 order code and the Microsoft operating system and 'Windows' which effectively emulates the MacIntosh. The Intel 486 chip using MS/DOS and windows linked to a laser printer as an ensemble essentially constitutes a dominant design. Companies that push beyond that configuration will probably find that they will not appeal to a larger group of customers."[11] As noted above, Langlois comes to a similar conclusion stressing that, "a dominant design emerges as a result of both technological and market learning."[12]

White further notes that the dominant design in a particular product can break down, broadly considered, without the occurrence of significant technological change in the product. For example, as documented by Womack, Jones and Roos (1992), the "lean" production system pioneered by Toyota, led not only to greater flexibility in production processes, but also to greater flexibility in product design, all without changing the basic technological paradigm of the automobile. This has led to a degree of competitive turbulence in the industry characteristic of an earlier period, though not to increased entry. Wheelwright and Clark (1993) have suggested that the ability of Japanese automakers to accommodate frequent though small changes will allow them to outpace firms that intend to introduce fewer but larger technological changes even when such changes are of a more radical nature. This certainly seems to be the case currently in their use of lighter weight materials. And a lighter automotive structure will be a prerequisite either to much more fuel efficient autos, or in the longer term to a successful electric vehicle.

Similarly, the television business is going through a dissolution now, high definition television notwithstanding. The current television receiver is still widely accepted, but the network model of broadcasting organization pioneered in the days of radio is simply vanishing under the onslaught of new organizational forms and systems for distributing programs. "Prime time" has become a less valuable commodity, while new methods of storage and distribution of programming have proliferated and programming content and viewing audiences have become far less predictable. Some markets will soon have literally hundreds of channels as well as movies distributed on demand in addition to videotape and videodisc distribution. One might even speculate that such a proliferation of services will be the catalyst that will make high definition television desirable to a large enough segment of the market to enable its advance.

Another important issue relates to the identification of a dominant design. It is clear that attempting to define or anticipate the appearance of a so called dominant design simply by mapping features and functions of the product alone is doomed to frustration. The foregoing arguments clearly indicate that the emergence of a dominant design is also strongly influenced by firms' possession of collateral assets, by government regulation and intervention especially around standards setting, by strategic maneuvering at the firm level and by interactions between users and producers. For example, in the case of the typewriter the widespread acceptance of the QWERTY keyboard was a result not only of the technical factors described in the case, but also of the invention of touch typing by a typing instructor. Touch typing greatly increased typing speeds reinforcing both the acceptance of the typewriter as a tool and the primacy of the Underwood Model 5 and QWERTY on which it was based. With that change the limiting factor became the human condition - the stock of widespread typing skills centered on a specific machine configuration. Thus, QWERTY has stayed unchanged through generations of product technology: electric typewriters, hardware based word processors and today personal computers. Neither the Dvorak keyboard representing a small advance over QWERTY, or various chorded keyboard designs representing potentially much greater advances have made any significant inroads in the market. However, many chorded commands and functions are being imbedded within the standard keyboard to take advantage of the power and flexibility of the personal computer and its software.

White suggests that the idea of dominant designs can best be understood in terms of information economies. Thus classical mass production can be understood as an attempt to embed information concerning best manufacturing practice in, for example, a set of dies and fixtures. Today there is less and less reason why all cars must be the same stemming purely from information economies. If that is true then the determination of what is or is not a dominant design will increasingly shift from the producer to the user interface.[13] A fruitful direction of work may be to analyze a few industries in depth to create and test multi-variate models of factors such as market factors, collateral assets, regulatory factors, network externalities, and so on related to firms' survival and success, with the crystallization of a dominant design being one factor among many (Christensen, Suárez and Utterback, forthcoming, Carroll 1993).

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1 Positive network externalities arise when a good is more valuable to a user the more users adopt the same good or compatible ones (Katz and Shapiro 1985).

2 As Teece 1986 and others have noted, the dominant design model is better suited to mass markets where consumer tastes are relatively homogeneous. Also, our claims only extend to assembly manufacturing industries. As Utterback (1994) has argued elsewhere, the hypotheses stated here are of less relevance to

the case of non-assembled products such as rayon or glass, in which innovation in the production process is an earlier and more central theme.

3 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 case below after presenting data from the United States.

4 The rapid degree to which new information technology is making possible more flexible production processes and to which it is allowing designers of products to engage in "mass customization" (Pine, 1993) may undercut this argument rooted as it is in obsolescent production techniques.

5 Abernathy (1978) and Fabris (1966) independently made this assessment from primary data. Eighty-five percent of the innovations classified as major by Abernathy are similarly classified by Fabris.

6 We are grateful to John Rydz, a participant in the early RCA developments for the information given here.

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

8 The data for foreign firms is displayed in Figure 11 below. Non-U.S. firms are not only, but mostly, Japanese in our data.

9 Brooks, 1985, P. 330.

10 There is a complex story here which needs more examination than can be given in this review. The earlier years were ones in which calculators were assembled first of thousands, then hundreds of parts. The U. S. peak marked the introduction of the "calculator chip" which seems to have been quickly adopted in both countries at the same time that many firms failed in both. Perhaps the Japanese advantages in manufacture are most pronounced in those industries that require many manufacturing and assembly steps. Perhaps entry barriers are lower in Japan in relatively small markets such as calculators than in larger markets.

11 Interview by the author with George R. White, February, 1993.

12 Robert N. Langlois, 1991.

13 Interview by the author with George R. White, February, 1993.

Table 1. A List of Dominant Designs By Industry

Industry	Dominant Design	Date	Source
Typewriter	Underwood's Model 5; Hess's innovations	1906	Engler, 1969
Automobile	All Steel, Closed body	1923	Fabris, 1966; Abernathy 1978
Television	21-inch set; adoption of RCA's technical standards	1952	John Rydz; Televisic Factbook 1949-89
TV Tubes	All-glass, 21 inch tube	1956	John Rydz; Televisio Factbook 1949-89
Transistor	Planar Transistor	1959	Tilton, 1971; Braun & MacDonald, 1978
Integrated Circuit	Multiple designs in rapid succession		Dataquest; Flaherty
Electronic Calculator	Calculator on a chip	1971	Majumdar, 1977
Winchester Drives	3 1/2 Inch Drive	1983	Christensen, 1992
Supercomputers	D.D. not yet identified, but we speculate it will be a variant of the hypercube architecture		Afuah & Utterback, 1990

Figure 1. Design hierarchies and dominant designs.

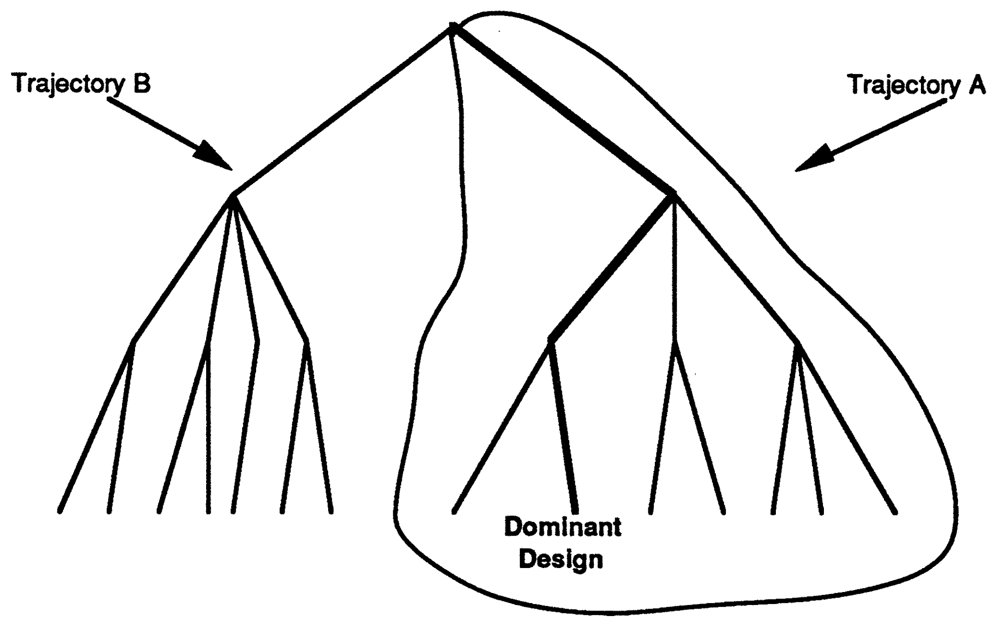

Figure 2. Summary chart of number of participants in different industries in the U.S.

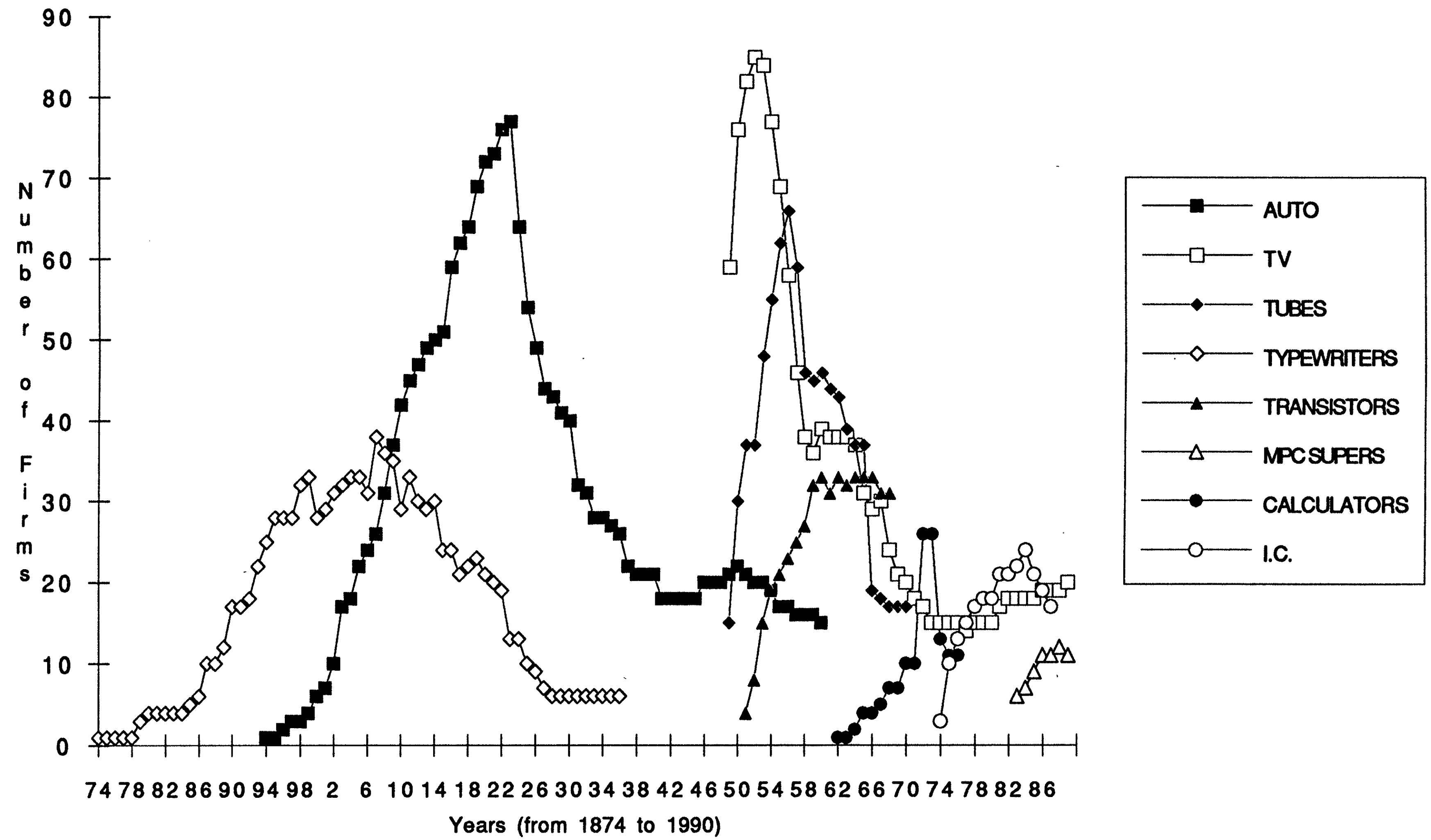

Figure 3. Number of firms participating in the typewriter industry in the U.S.

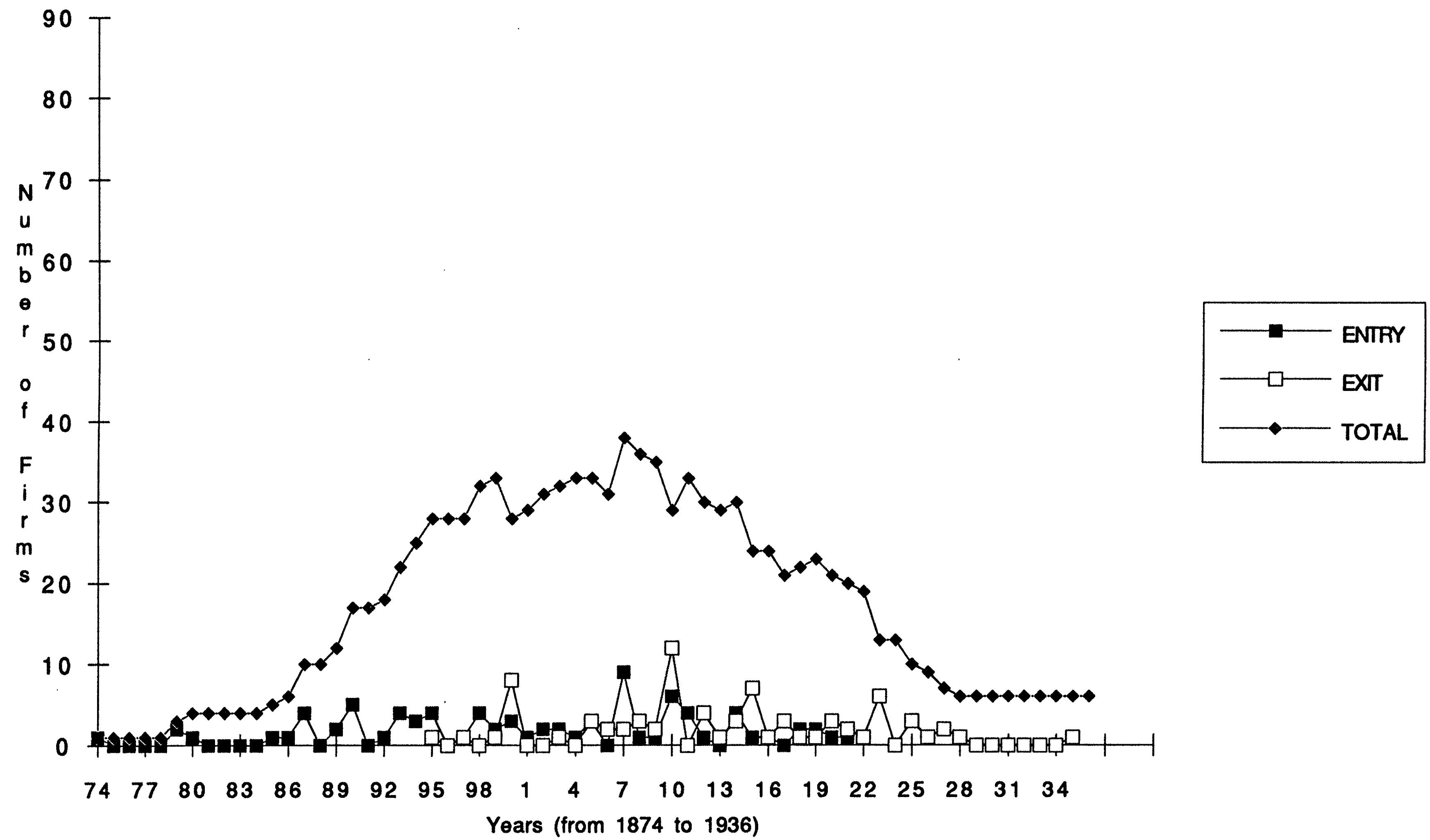

Figure 4. Number of firms participating in the television industry in the U.S.

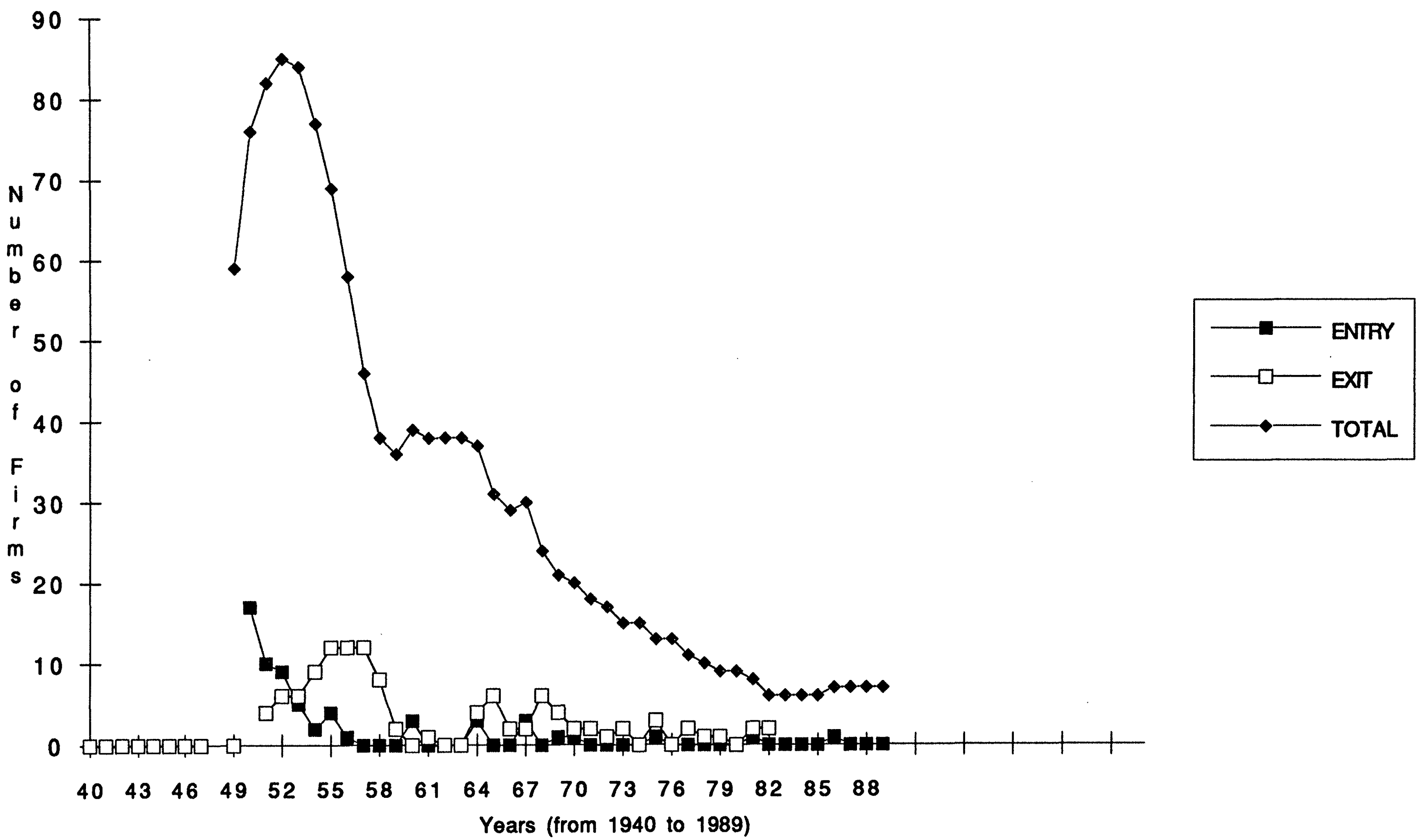

Figure 5. Number of firms participating in the cathode ray picture tubes industry in the U.S.

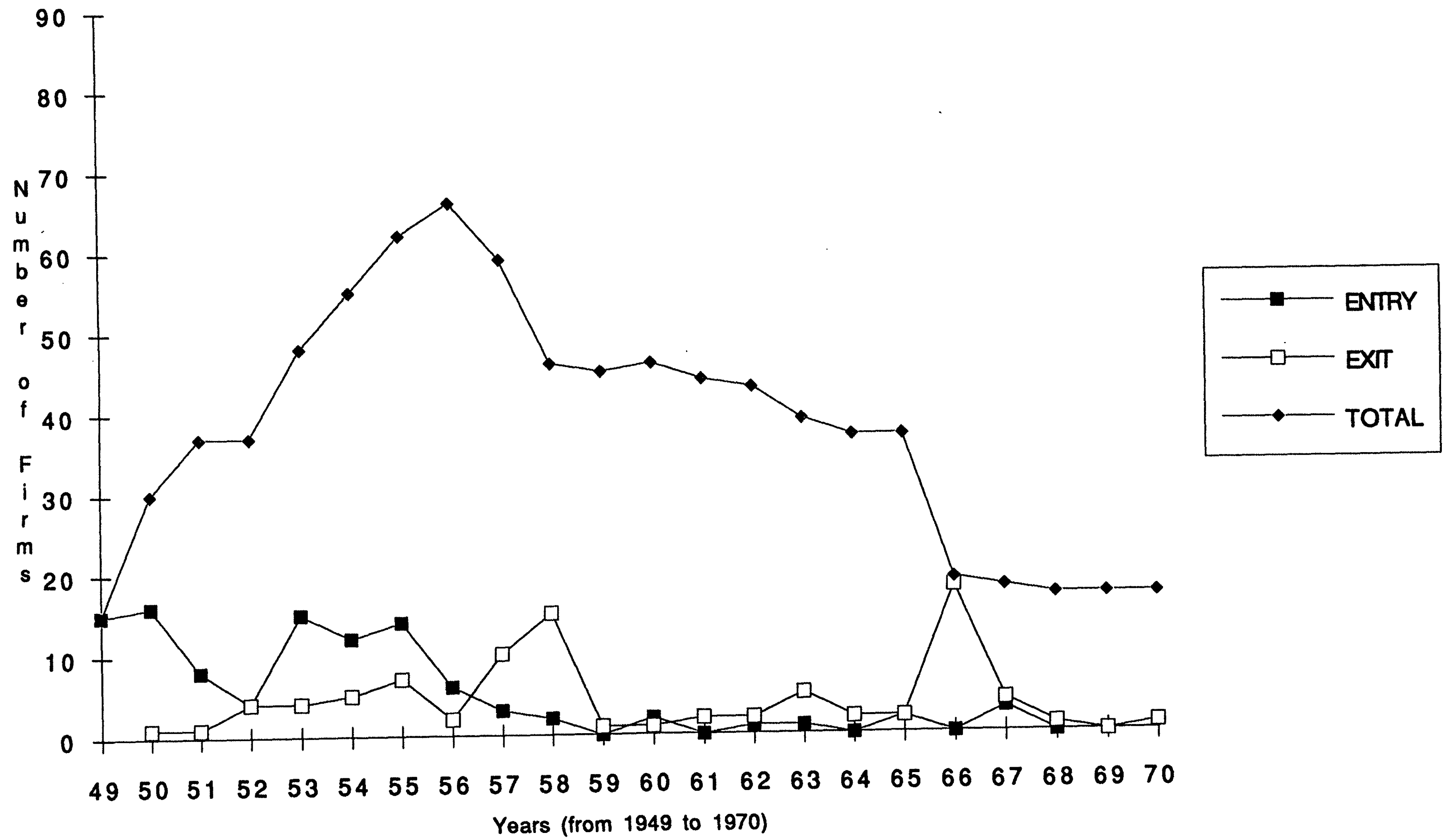

Figure 6. Number of firms participating in the transistor industry in the U.S.

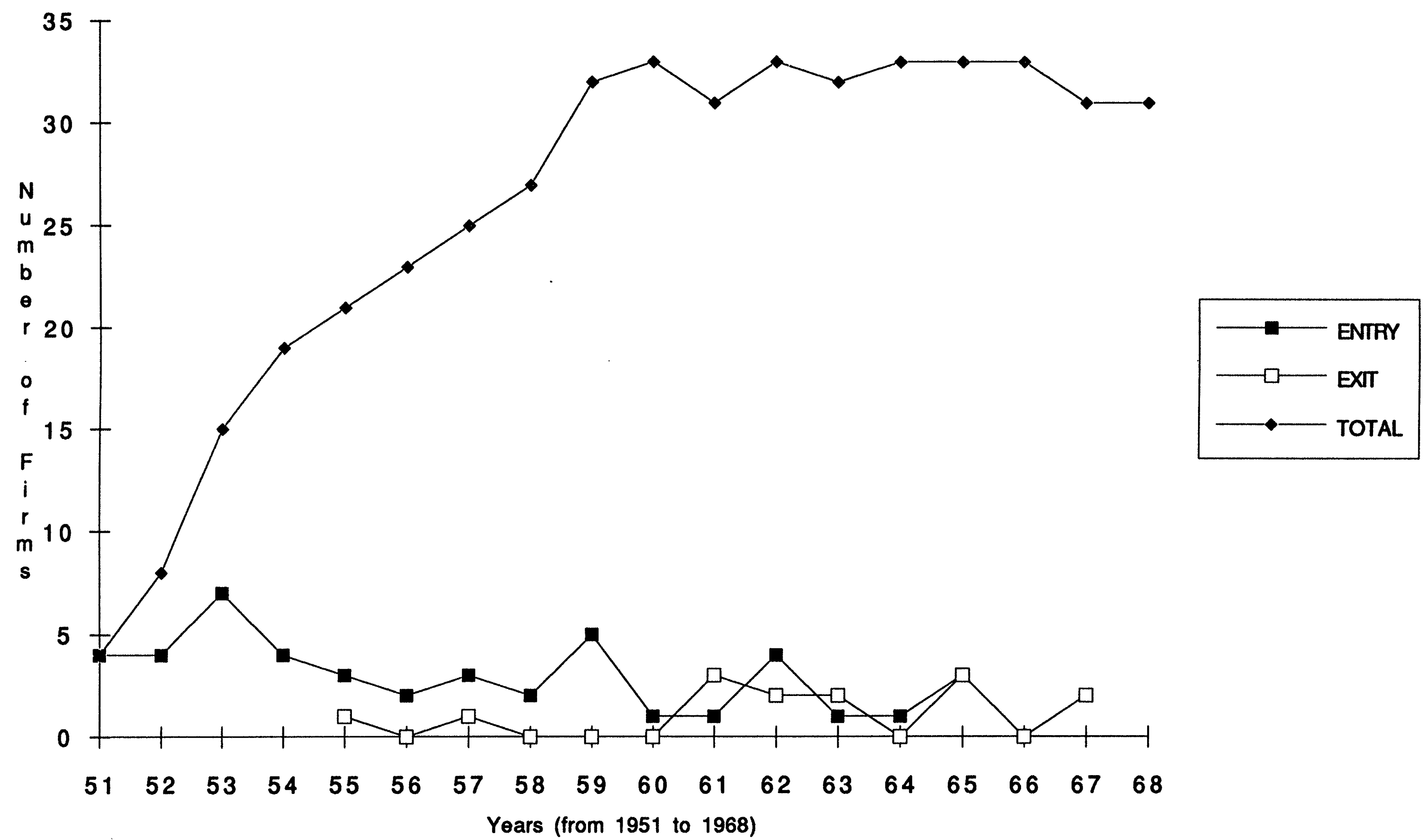

Figure 7. Number of firms participating in the integrated circuits industry in the U.S.

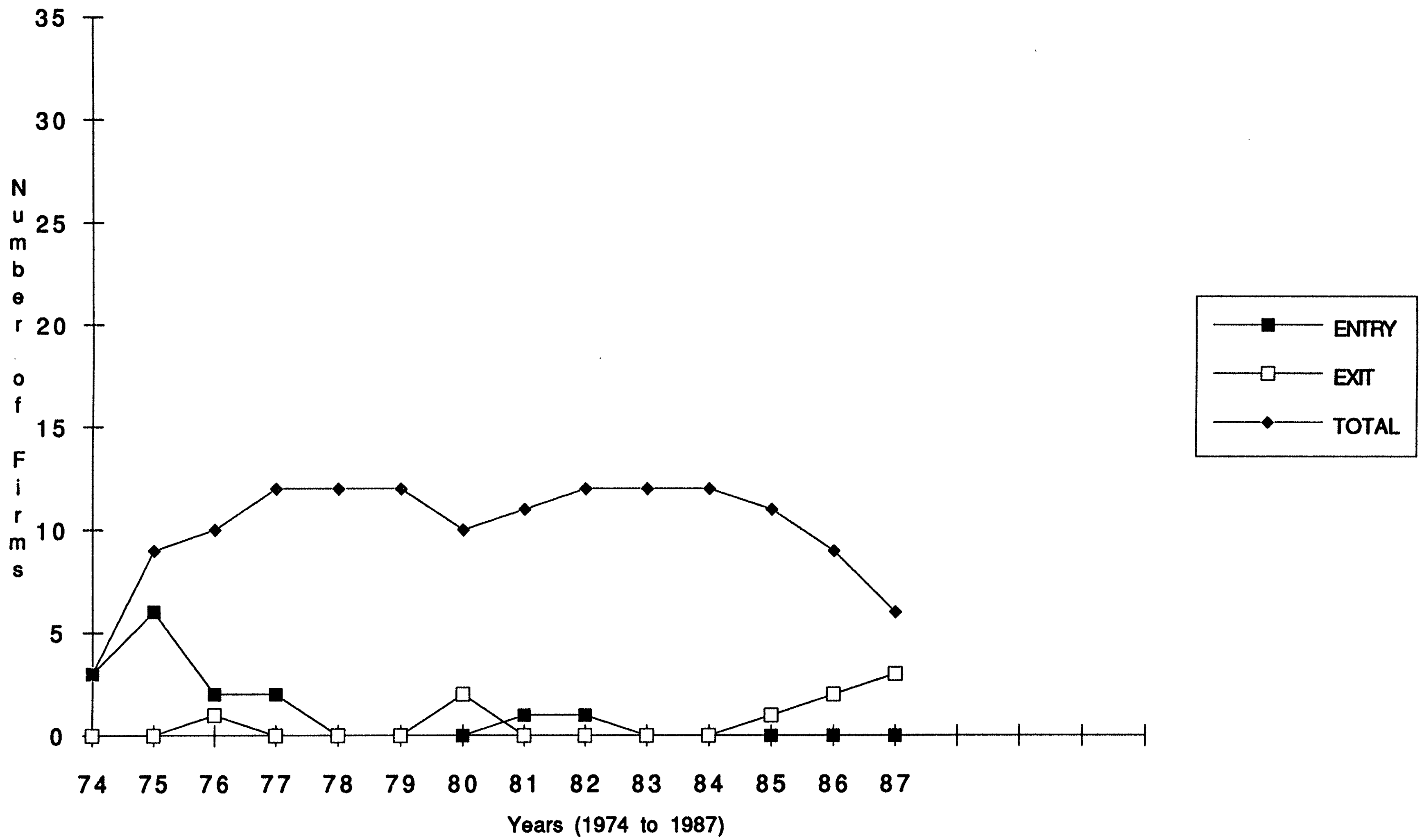

Figure 8. Number of firms participating in the electronic calculator industry in the U.S.

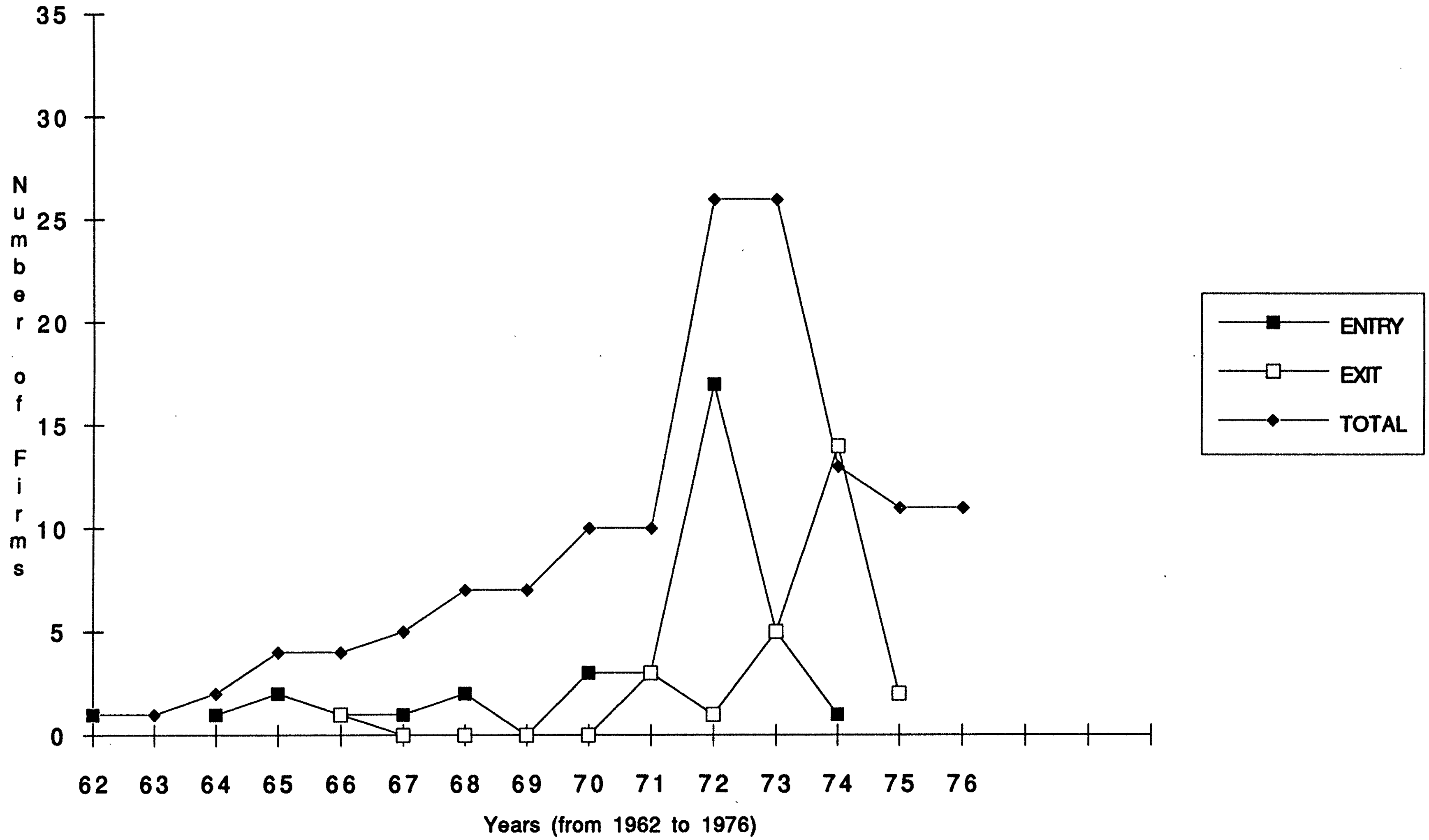

Figure 9. Number of firms participating in the winchester drive industry in the U.S.

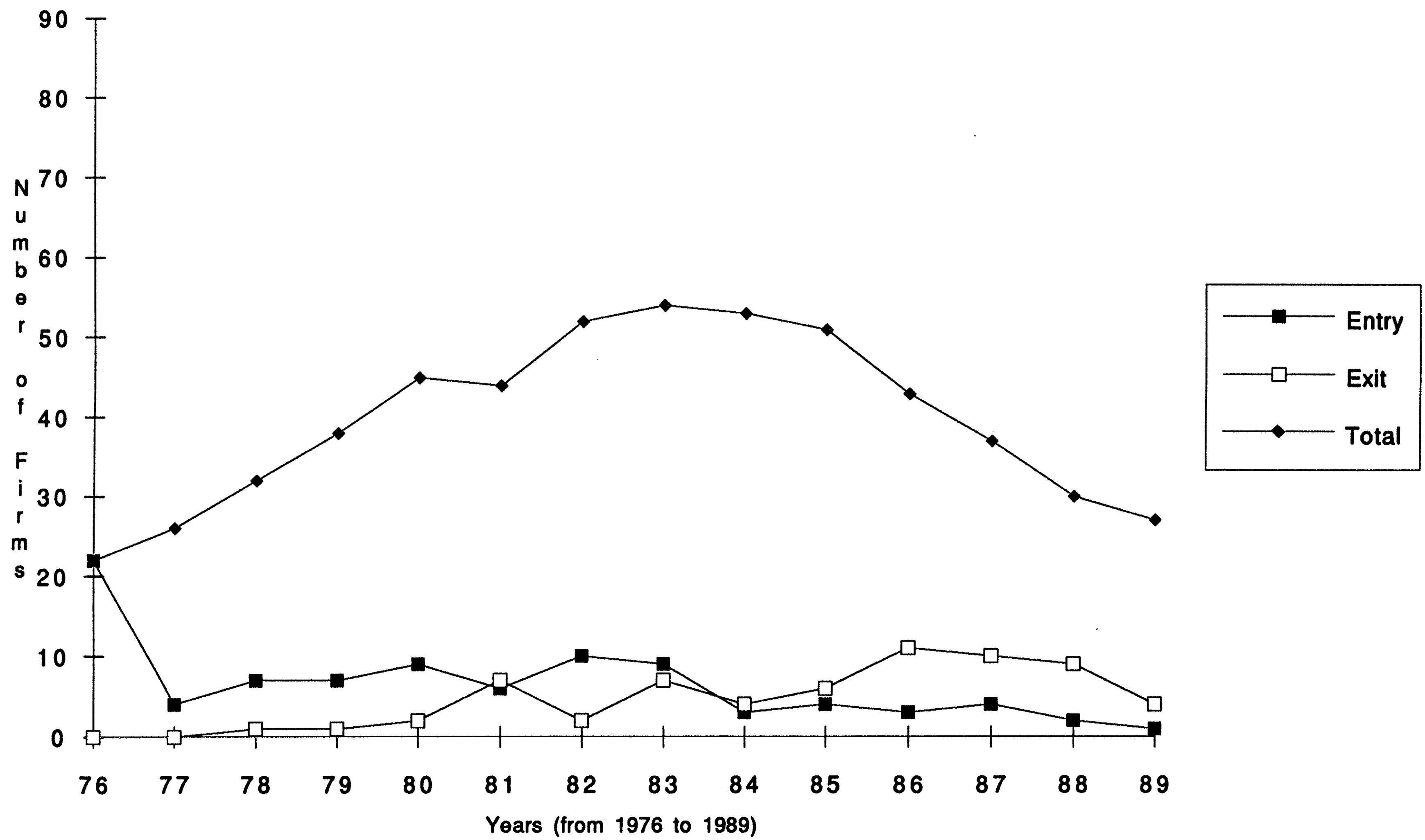

Figure 10. Number of firms participating in the massively parallel supercomputer industry in the U.S.

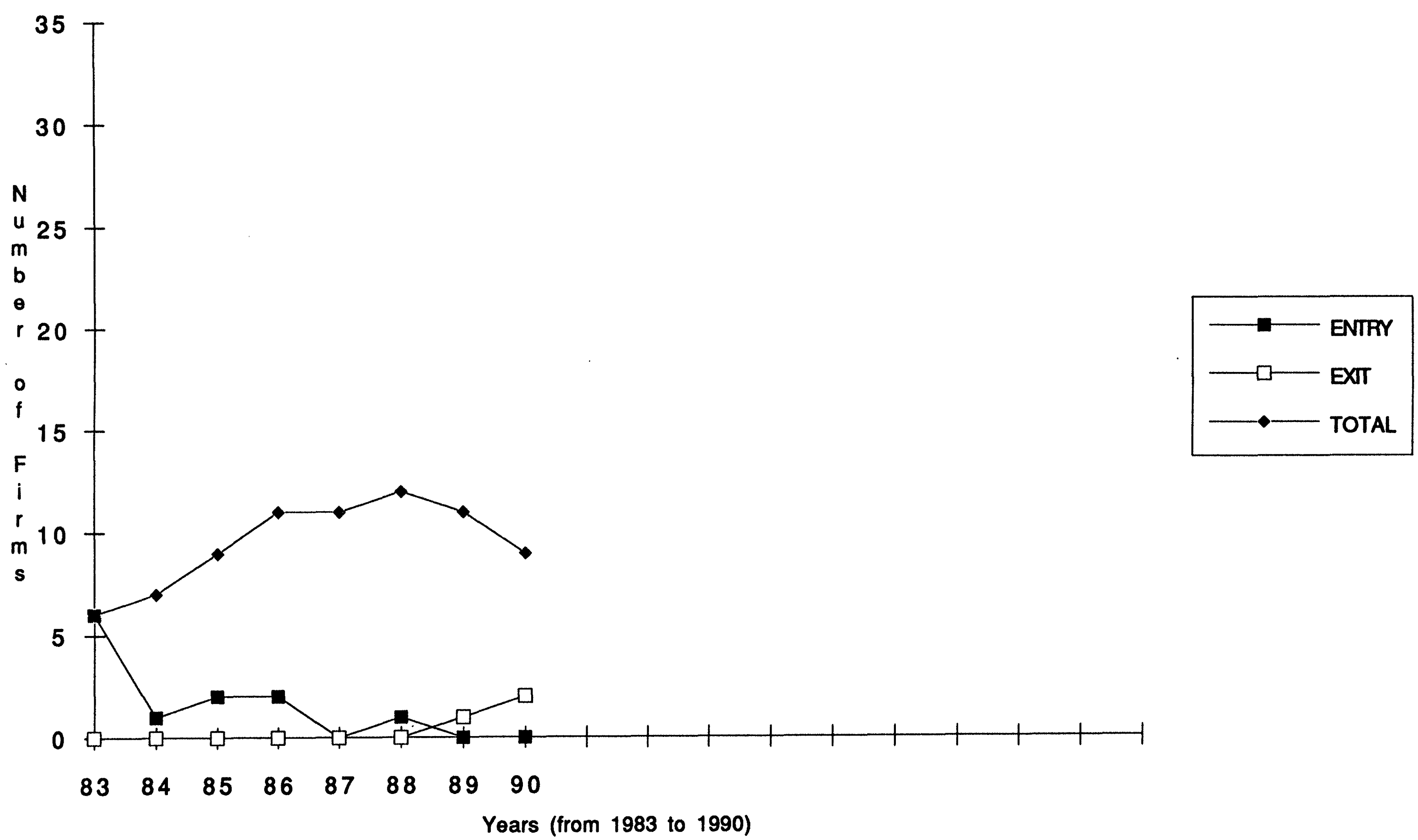

Fig. 11. Summary chart of number of participants in different industries in Japan.