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Managing through Cycles of Technological Change

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Introduction

After the age of efficiency in the 1950s and 1960s, quality in the 1970s and 1980s and flexibility in the 1980s and 1990s, we now live in the age of innovation. Increasingly, industry is applying new technology to new products and services. Even the strongholds of economists, with their elephant-grey suits, are changing rapidly and new financial products are developed in larger numbers and at a faster pace. In these organizations, technology has become one of the main engines of change and innovation. If banks and insurance companies are not fast enough with their innovations, they might even encounter software houses, such as Microsoft, making inroads into their territory. In those industries where innovation is already commonplace, companies compete on time. Being the fastest with respect to new features, better quality, more attractive styling and so on is the way to beat the competition.

Innovations may come in many different shapes. The term 'innovation' has been defined by the great Australian economist Joseph Schumpeter as: the commercialization of all new combinations based upon the application of:

- new materials and components;
- the introduction of new process;
- the opening of new markets; and
- the introduction of new organizational forms.

Innovations may also come in many different sizes. We distinguish small, incremental, large, breakthrough and radical innovations, modular and architectural innovations. Often radical innovations are composed of a number of smaller ones that, once combined, lead to a breakthrough. The first

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microcomputers were developed in the 1970s in backyards by teenagers in California. They were composed of components that already existed and could be bought in the shops. The innovation started as a new assemblage of existing components. Rebecca Henderson and Kim Clark (1990) have called this an architectural innovation. The new product opened a new market. When the market developed further and the market's needs were better articulated, adaptation of components started to fit in the new type of product. In a short period of time, a whole new industry evolved from it. This shows how the introduction of a new technology or a new combination of technologies led to a new market. This led to the emergence of new industrial organizations and to the development of improved and new technologies.

We are managing what Peter Drucker has termed "the age of discontinuity." Examples of revolutionary technological changes that transform industries abound. Flat screen displays have dominated the bulky cathode ray tubes in television screens and computer monitors. Optical disks capable of storing billion of bytes have supplemented the magnetic fixed disks for mass computer storage and USB Flash drives have now supplemented the optical disks. Lithium batteries have superseded lead-acid technology and in the field of telecommunication the shift from 2G to 3G has already taken place.

Such discontinuities bring about "creative destruction," the overturning of established industry structures, which Schumpeter saw as the fundamental engine of capitalist process. Building on a tradition extending back to the 1950s (Strassmann 1956 and Bright 1964), Richard Foster (1986) argues that industry leaders become losers because they have difficulty managing technological discontinuities – movements from one technology to another with inherently higher limits. Foster's depiction of technological progression through a series of S-curves suggests that technological change follows a cyclical pattern. The best-known model of technological change, the Abernathy/Utterback model, originally viewed technological progress as a single cycle, leading toward more process and less product innovation and culminating in the productivity dilemma. Yet more recent updates of this framework in the early 1980s conclude that technological change is cyclical - "dematurity" can in effect set the clock back and return an industry from a "specific" to a "fluid" state.

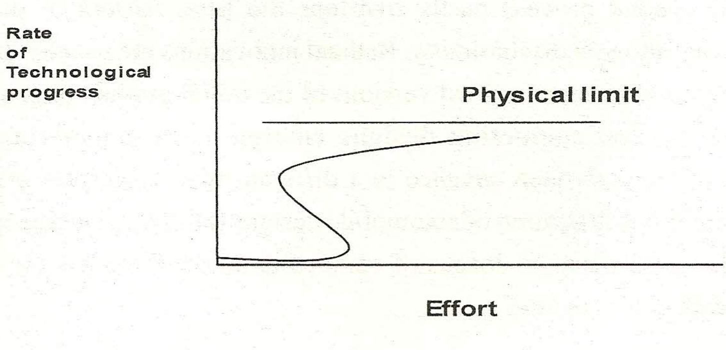
Technology Cycles

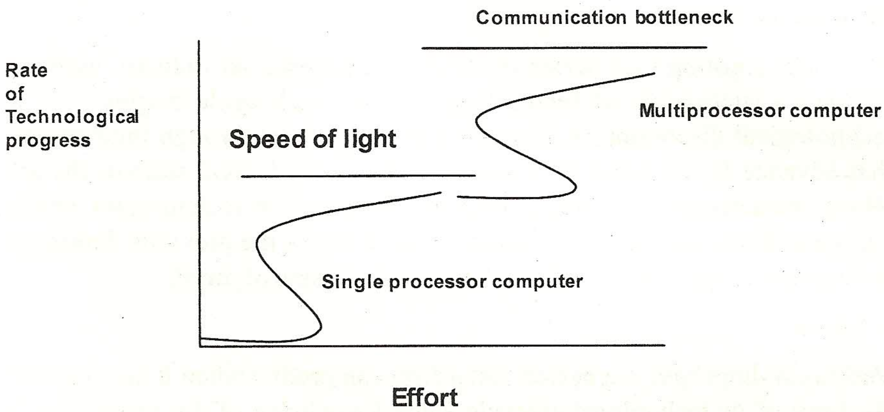
As Foster's notion of a series of S-curves suggests, an industry evolves through a succession of technology cycles. Each cycle begins with a technological discontinuity. Discontinuities are breakthrough innovations that advance by an order of magnitude the technological state-of-the-art which characterizes an industry. They are based on new technologies whose technical limits are inherently greater than those of the previous dominant technology along economically relevant dimensions of merit.

S Curve

Various authors have suggested that a firm can predict when it has reached the limit of its technology lifecycle using knowledge of the technology's physical limits (Ehrnberg 1996). Foster, for example, argues that the rate of advance of a technology is a function of the amount of effort put into it, and he follows the S curve.

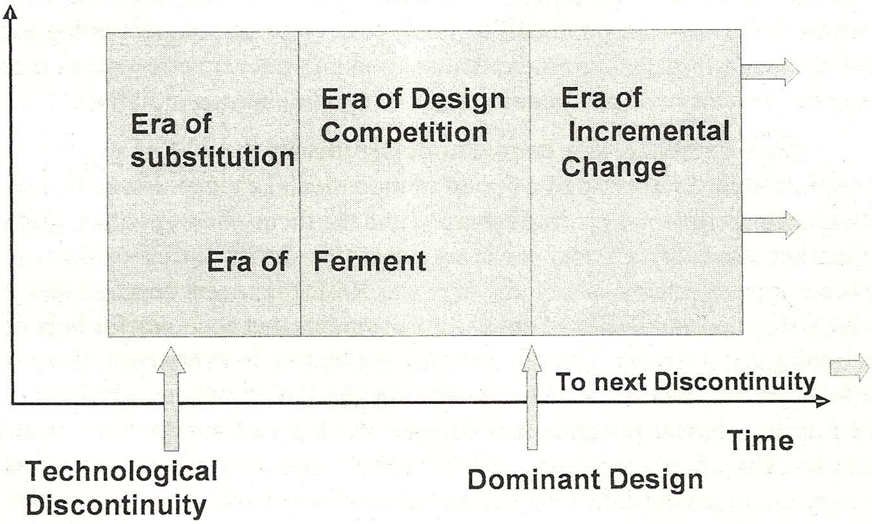
Technological progress starts off slowly, then increases very rapidly, and then diminishes as the physical limits of the technology are approached. Eventually the return on effort becomes extremely small. A new technology whose underlying physical properties allow it to overcome the physical limit of the old technology must be used. Supercomputers serve as a good example. For years they were designed using single-processor architectures until their ability to compute started approaching a physical limit – the speed of light. Multiprocessor architectures such as massively parallel processors give rise to a new S curve, with new physical limit now being the communication bottlenecks from the many processors whose actions must be coordinated. According to Foster, computer makers should have been able to foresee the end of the single-processor architectures by looking at the diminishing returns on efforts put into improving single processor designs.





Each technological discontinuity inaugurates a new technology cycle. The breakthrough initiates an era of ferment characterized by two processes. First, the new technology displaces its predecessor during substitution. Though Foster argues that new technologies appear only when the old technology reaches its technical limits, often the older technology improves markedly in response to the competitive threat. Gaslight technology, for example, improved dramatically in the decade after the introduction of the Edison electric light, Apple has pushed the limits of 8-bit microcomputer technology forward dramatically since the appearance of 16-bit and 32-bit replacements for the once dominant Apple II. Despite these improvements, Fisher and Pry (1971) demonstrate that in many cases, the substitution process proceeds with mathematical inevitability once a small initial penetration is achieved.

The second process partly overlaps the first. An era of design competition follows a discontinuity. Radical innovations are usually crude, and are replaced by more refined versions of the initial product or process. Typically, several competing designs emerge, each embodying the fundamental breakthrough advance in a different way. Examples include the tremendous proliferation of automobile designs following Duryea's first auto or the appearance of dozens of competing airplane models after the Wright brothers' invention.



Adapted from Tushman and Anderson, *Managing Strategic Innovation & Change,* 1986.

The design competition culminates in the appearance of what Abernathy and Utterback (1978) term a "dominant design," also called a "technological guidepost" by Sahal (1981). This design is a single basic architecture that becomes the accepted market standard. Dominant designs are not necessarily better than competing designs, and they often pioneer no innovative features themselves. Rather, they represent a combination of features, often pioneered elsewhere, that sets a benchmark to which all subsequent designs are compared. Examples include the IBM 360 computer series, the Fordson tractor, and the Ford T automobile.

The dominant design establishes a stable architecture for the technology and enables firms to focus their efforts on process innovations that make production of the design more effective and efficient or on incremental innovations to improve components within the architecture. Utterback and Abernathy termed this phase "specific" because innovations in products, materials, and manufacturing processes are all specific to the dominant design. For example, in the United States the vast majority energy production is based on the use of fossil fuels (e.g., oil, coal), and the methods of producing energy based on these fuels are well established. On the other hand technologies that produce energy based on renewable resources (e.g. solar, wind, hydrogen) are still in the fluid phase. Organizations such as Royal

Dutch/Shell, General Electric, and Ballard Power are experimenting with various forms of solar photocell technologies, wind turbine technologies, and hydrogen fuel cells to find methods of using renewable resources that meet the capacity and cost requirements of serving large populations.

The emergence of a dominant design marks the end of the era of ferment and the beginning of a period of incremental change. Here, the rate of design experimentation drops sharply, and the focus of competition shifts to market segmentation and lowering costs (via design specification and process improvement). Many scholars and R&D managers contend that it is the patient accumulation of small improvements that accounts for bulk of technological progress. Though this may not be true in every case, there is little doubt that once a design becomes a standard, it establishes a trajectory for future technical progress and changes the basis of competition in the industry. This era of competition based on slight improvements on a standard design continues until the next technological discontinuity emerges to kick off a new technology cycle.

Influence of "Competences"

The nature of the technology cycle is greatly affected by the dimension of competence. Well some discontinuous innovations are competence-destroying. They obsolesce existing know-how; mastery of the old technology does not imply mastery of the new. Firms must embark on a new learning curve which is essentially unaffected by the firm's existing know-how, and technical professionals require new training. The transistor illustrates a competence destroying product innovation; mastery of vacuum tube technology proved as much a hindrance as a help to engineers trying to understand semiconductor electronics, and the learning curve for firms struggling to master the technology was unaffected by the firm's vacuum tube know-how.

Other discontinuous innovations are competence enhancing. These breakthroughs push forward the state-of-the-art by an order of magnitude, but build on existing know-how instead of obsolescing it. Thus the turbofan jet engine is a competence-enhancing product innovation. It marked.y improved engine performance, but is built on existing know-how instead of overturning it.

Both product and process innovations may either enhance or destroy existing competences. Yet there is a fundamental difference between product and process innovations. Product innovations normally affect more links in the value chain than do process innovations. The customer must be made aware of new products. Often he is not aware of process innovations. New products often require distribution channels and suppliers different from those which serviced older products. Process innovations usually make the product better and cheaper without necessarily disrupting upstream and downstream linkages. Thus, a key factor is not only whether the core technical know-how of an industry is disrupted by an innovation, but whether links in the value chain are overturned or reinforced by the new technology.

Characterizing the Technology Cycle

Discontinuities are generally uncommon, and their frequency varies greatly by industry. Nonetheless, they characterize both young and mature industries. A single dominant design always emerges following a discontinuity, except in two situations. When one discontinuity follows another very rapidly (within 3-4 years), a dominant design may not have time to emerge before the second new technology displaces the first. When several producers patent their own proprietary processes and refuse to license to others, a dominant design may not emerge.

The original discontinuous innovation never becomes a standard. Some improved version of the initial breakthrough becomes the basis of dominant design in every case. Further more, more often than not, dominant design lags behind the state-of-the-art at the time they are introduced. The winner of the design competition is seldom at the industry's performance frontier; typically the industry pushes the state-of-the-art forward during the era of ferment, then standardizes on a design that is behind the leading edge of the technology.

The length of the era of ferment (the lag from introduction of the new technology to establishment of a dominant design with 50% of the market) depends on whether the discontinuity enhances or destroys existing know-how. It takes longer for an industry to converge on a dominant design following competence destroying discontinuity than it does to converge on a dominant design following a competence enhancing discontinuity. When existing know-how is reinforced, the industry arrives at a standard relatively rapidly; when it is overturned, it takes considerably longer for the design competition to culminate in a single technological guidepost. Furthermore, when a series of discontinuities enhance the same underlying competence, the length of the era of ferment grows shorter with each successive technological cycle, bolstering the argument that the more familiar the underlying know-how, the easier it is to reach a standard.

Discontinuities and Dominant Designs

A key competitive question is: When does a discontinuity overturn an industry or when do leaders become losers? Firms which possess know-how – the veterans – are most likely to build on that expertise. It is also easy to understand why competence-destroying innovations are pioneered by newcomers. The new technology obsolesces what the veterans know, temporarily knocking down barriers to entry. Veterans are reluctant to adopt the new technology because it wipes out their considerable investments and forces them to change in fundamental ways. It is in this case that leaders are most likely to become losers. However, competence-destroying process innovations are typically pioneered by veterans, despite the fact that they are obsolescing their own process know-how. This paper argues that veterans still are able to exploit strengths upstream and downstream in the value chain following a process discontinuity and only their core technical know-how is overturned. As a result, veterans are willing to write off investments in existing facilities and expertise to exploit the price/performance advantage of the new technology.

Finally, dominant designs are always pioneered by veterans, whether or not they build on or destroy competences. The revolutionary is seldom the standard-setter. Recall that dominant designs seldom are state-of-the-art, and that industry experience is needed to understand what the market needs in a standard.

Discontinuities

	Product	Process
Competence Destroying	Newcomer	Veteran
Competence Enhancing	Veteran	Veteran

Dominant Design

	Product	Process
Competence Destroying	Veteran	Veteran
Competence Enhancing	Veteran	Veteran

Adapted from Tushman and Anderson, *Managing Strategic Innovation & Change,* 1986.

Creative Destruction

Industries are characterized by waves of foundings and failures. A period when the failure rate is unusually high is often termed a "shakeout." The conventional wisdom is that overcapacity or downturns in demand cause shakeouts. The inability to adapt to a new technical order seems to kill more firms than the inability to withstand a recession in the industry.

Implications for Managers

The model of technology cycles provided here is one step toward developing what Foster terms "a language and a facility for talking about and directing technology." It allows managers in different industries to organize their view of the industry's technical history, and to compare the effects of various types of innovations on the industry's structure. Beyond this, the paper draws four principal lessons for managers from this paper.

1. Expert Discontinuities. They do not happen frequently, but they do occur even in mature industries, and they are watershed events. When evaluating potential discontinuities on the horizon, consider whether they enhance or destroy fundamental competences in your industry. Consider developing competencies that survive technological revolutions, such as flexible manufacturing capability or strong distribution channels.

2. When discontinuity appears, expect an era of ferment culminating in a single dominant design. Expect several designs to compete and expect one to emerge as a winner. The dominant design will seldom be state-of-the-art architecture; it is usually introduced by industry veterans, and the time it takes to reach a design depends on whether the discontinuity is competence-enhancing or competence-destroying.

3. Realize that technological revolutions may be introduced by an industry newcomer, but the group of firms that adopt it earliest typically includes a majority of veterans. But more often than not, the pioneers of discontinuities are competitors.

4. Top management always pays attention to industry recessions and is willing to make painful cost-cutting moves when demand drops. Yet it is not this form of competition that threatens the very survival of the firm and its rivals. Maintaining the organization's ability to navigate the rapid creative destruction brought in by technological discontinuities is the key to fulfilling management's first duty to shareholders –

preserving their capital by ensuring the continuance of the enterprise. The ability to direct a firm's marketing and financial operations helps top managers improve its profitability. The ability to direct process and product innovation affects not only profitability but the viability of the firm itself in a world of technological upheaval.

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