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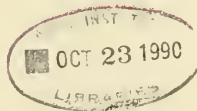
Technological Discontinuities
The Emergence of Fiber Optics

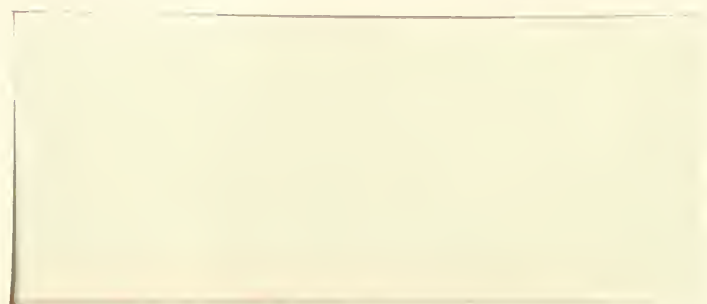
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WP # 3199-90-BPS

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Technological Discontinuities
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ABSTRACT

Prior descriptions of technological discontinuities by Utterback and Kim and by Tushman and Moore are restricted in their competitive sphere to a single attacker and a single defender. In reality, the situation is often much more complex, and the emerging technology can be perceived in many different ways by different industry participants. The purpose of this paper is to examine optical fibers as a technological discontinuity in an industry which has a complex structure. Clearly, competitive strategy has had an important role to play in the way in which industry participants have mastered technological change.

Technological discontinuities are frequently discussed in the literature of business strategy with reference to an attacker and a defender - two companies separated by a technological "divide". In order to attempt a more comprehensive analysis of the strategies pursued by competitors during a period of discontinuous technological change in an industry, we decided to explore the product and process development decisions and actions of a number of competitors, as well as their technological resources and market positions in detail. As an illustration we chose to explore the technological discontinuity which accompanied fiber optics' assault on copper cable in the telecommunications markets in the United States. The fiber optics discontinuity meets our needs, as it is certainly not restricted to just a single attacker and defender. It is a timely and current case, and one of the present authors (McCormack) has been intimately involved in the development of fiber optics technology for the past decade. Hence this work will examine perceptions of the optical fiber-copper cable discontinuity from the perspectives of five different industry participants located on both sides of the divide and having widely varying resources and market positions .

The second author (Utterback) joined in this collaboration, because he had recently surveyed a wide variety of case studies and industry studies seeking to understand corporations' responses to technological discontinuities in general terms and to develop a set of hypotheses or model (Utterback and Kim, 1986). This model's prescriptive character is used to advantage in highlighting issues for the management of technology and the results of the case studies show that present definitions of "discontinuities" are too simplistic. It is hoped that the "richer perspective" obtained here will add to the ongoing work on technological evolution and industry discontinuities.

In a recent book espousing the "attacker's advantage" Foster clearly explains how dogged persistence in investing in an established technology can become a liability when a new, totally different

technology appears in the scene. In a given industry the new technology can follow a performance curve similar in shape to that of the old technology, but its starting point will be higher up the "performance parameter" scale and its "natural limit" will consequently be higher than that of the existing technology (Foster, 1986). It is important to compare like with like when discussing discontinuities between functions of technological progress, a fact that Foster doesn't bring out in his treatise on attackers and defenders. He fails to define the unit of analysis in many of his examples and limits his discussion to unidimensional progress curves. In reality the many dimensions of technology progress independently in a highly complex manner.

Cooper and Schendel's (1976) elegant and pathbreaking comparative case studies have shown that a new product technology is more likely to be introduced by an outsider, rather than a traditional competitor, and the aggressor is often a small "start up" venture. However, a new process technology for the old product would be expected to emerge from traditional competitors (Utterback and Nolet, 1989). Given that the new technology has the potential to substitute for the old and provide clear advantages to the end user, the established company is placed in a disadvantaged position and must reconsider its strategy. It is difficult for a large organization to quickly embrace a radical new technology and maintain its prominent position in the market for many reasons, among them large investments in place in technical knowledge, designs, people and equipment that may not be adaptable to the new requirements. Witness the demise of the leading vacuum tube producers when the transistor emerged in the 1950's. Companies wishing to successfully make the transition from the old to the new technologies must carefully organize themselves to facilitate a balanced change in strategy, culture and structure of the company in order to manage the discontinuity between the old and new technologies.

It can take a decade or more to complete the switch from old to new technologies and hence it is often too late to engage in a new technology when the signs become clear that the existing technology is in decline. A successful shift to the new technology must begin long before the decline in the old technology has set in. Forecasting the beginning of a decline by carefully reading the signs available in the earlier stages of the technology lifecycle is essential in order to correctly time the transition from the old to the new technologies.

Utterback and Brown discuss such environmental monitoring using the example of the silver chemistry based photographic business and point out that focusing on the traditional competition is insufficient. Relevant information must be gathered from potential entrants outside the established industry such as electronics and television (Utterback and Brown, 1972, p.5). A change in technology or market conditions often allows companies from outside a particular strategic group to lower the mobility barriers and seek entrance.

Conversely, the old technology usually will continue to improve, and to improve at a dramatically faster rate, after the introduction of the new technology, because the traditional competitors increased investment in research and development in order to fight off the aggressor. This is to be expected because the established companies have had significant investment in plant and equipment which is difficult to write off. Retrenchment of the rate of progress of the old technology may make established competitors all the more reluctant to embrace the new - to cross the divide. An interesting point emerging from Cooper and Schendel's (1976) study was that most of the traditional companies divided their resources and invested in both the old and the new technologies. It is this divided strategy which was largely unsuccessful in producing a strong competitive position in the new technology.

Utterback and Kim (1986) contend that discontinuities in technologies frequently occur. In order to be a significant threat an

invading technology must obviously be potentially superior along at least one performance dimension even though it may start off being inferior to the established technology. The invader will often start in a small market where its unique characteristics are crucial. It is here that the established companies will emphasize the differences in performance between the old and the new along traditional dimensions of measurement without reference to unique dimensions of the new, or its improving the cost/performance criterion.

Utterback and Kim discuss the process of radical innovation - innovations invading stable businesses, in terms of an earlier model of evolutionary technological change (Utterback and Abernathy, 1975) by postulating four different patterns of discontinuous change. The hypothesised patterns are based on the varying degree to which production process and/or market linkages are disrupted by a particular innovation. These same patterns of change have been reinforced by Tushman and Anderson who describe them in terms of whether they are competence-destroying or competence-enhancing for the industry participants (Tushman and Anderson, 1986, p.439). Following a discontinuity these authors predict that industry uncertainty and munificence (ability to support growth) will both increase. Each of Utterback's and Kim's patterns will be described below, and we will discuss where the emergence of fiber optics can be placed in this typology.

Product Process Discontinuities

This pattern of discontinuity occurs when new firms entering the existing business introduce a product with very different properties from the existing ones. The new product is so unrelated to the existing one that traditional firms cannot use existing processes to replicate the new product since a new process is required. Although initially crude and expensive, the new product's higher performance in at least one dimension enable it to enter niche markets. As the dominant design (Abernathy, 1978) for the new product emerges, it introduces both major product and process changes compared to the

existing product which is being changed incrementally to improve productivity.

An example of product-process discontinuity is the displacement of vacuum tubes by transistors. Although crude when first introduced by Bell Labs (who did not manufacture vacuum tubes) they had potential advantages of size and energy efficiency. Major changes after their discovery led to the emergence of thin film field effect transistors with significantly improved temperature stability, noise and bandwidth characteristics. A similar story could be told of the emergence of electronic calculators, introduced in 1962 by companies such as Sumlock and Sharp, who were not manufacturers of electromechanical calculators. Rapid progress produced reliable, cheap machines which completely displaced their electromechanical competitors.

In both of these areas the pattern of technological change was initiated by an industry outsider and product and process change shifted from the "specific" state of the traditional product to the "fluid" state of the new product (Abernathy and Utterback, 1980). In these examples Tushman and Anderson would term the creation of a new product class or a substitute for an existing product as being a competence destroying product discontinuity. Such a discontinuity will favor new entrants who possess the knowledge and skills that established producers do not have.

Product Discontinuities

A product discontinuity occurs when a new or existing industry participant introduces a higher performance product which is basically similar to the existing one, but which exploits changing market opportunities. Because the new and old products are not widely dissimilar established firms can use their existing process know how to replicate the new product. The rate of change in process innovations is therefore expected to be less than those occurring in the product. Rapid price reduction of the new product

increases its price/performance ratio far above the existing product and the latter is eventually displaced.

A classic example of product discontinuity is the substitution of the model T by the model A automobile at Ford in the late 1920's. Ford invested heavily in plant and equipment to mass produce the model T and between 1908 and 1927 produced over ten million units. Changes in technology enabled GM to introduce an enclosed automobile in 1923 offering higher performance at a higher price. Ford met this new competition in 1927 by closing its operations, making 60,000 workers redundant and retooling to introduce the model A. Ford used its experience as a car manufacturer to use much of its existing production knowledge. Another example of a product discontinuity is the emergence of integrated circuits which replaced a product containing a large number of discrete transistors. Experience gained in the production of transistors could be transferred to the production of integrated circuits.

Tushman and Anderson (1986) would term these events competence enhancing product discontinuities, and because existing production "know-how" is transferable to the new product, established firms may be in an advantageous position.

Process Discontinuities

This pattern of change occurs when an established company produces essentially the same product but by a radically new or improved process in response to material shortages, government regulations or stiff cost competition. Non-assembled products such as glass, chemicals or steel often exhibit this pattern.

Examples are the displacement of the open hearth furnace by the basic oxygen process in steel making and the introduction of continuous casting of steel which is presently displacing the primary mill in the steel industry. Such examples of process substitution would be termed competence destroying by Tushman and

Anderson and they would expect outsiders to enter the industry. We hypothesize, quite to the contrary, that existing firms in the industry, albeit not necessarily the dominant firms in terms of market share, will be most likely to initiate process discontinuities (Utterback and Nolet, 1989). While the product in these examples essentially remains in the "specific" state the process is moved from "specific" to a new "fluid" state, in Abernathy and Utterback's (1980) terms.

Process Product discontinuities

This change results from a radical process innovation which, although it produces the same physical product, completely changes the products' strategic market position and new uses emerge. An example of such events is the on-site production of liquid oxygen which replaced bulk delivery and opened up new markets by removing existing entry barriers to other business segments. It is difficult to say whether Tushman and Anderson would term this pattern of change competence destroying or competence enhancing. It could be either.

The Sample of Firms to be Studied

We will be concerned here only with the manufacturers of communications grade optical fibers whose major market to date has been telecommunication systems. One method of segmenting the industry prior to analysis is to follow Porter's (1985) approach and take each participant and look at its market share, research and development ratio, level of integration, customers and other important factors and produce a series of "strategic groups". The emergence of fiber optics could then be discussed as a factor in changing mobility within the groups. Because we wish to concentrate on managing the emergence of optical fibers as a technological discontinuity which "forms" groups, we have chosen to segment the participants into five groups of different historical

perspectives according to the background of the company with respect to telecommunications. These groups are:

1. Outsiders - Companies not involved in telecommunications for example Corning, Dupont.
2. Telecommunication Companies for example AT&T, GTE.
3. Copper cable manufacturers for example Mohawk Wire and Cable, Times Wire and Cable, Simplex Wire and Cable, General Cable Corp, Belden.
4. Traditional illumination fiber manufacturers for example American Optical Corp, Galileo.
5. New start-ups for example SpecTran, Fibronics, Valtec.

Two companies - one from each of the first two groups - have played extremely important roles in the emergence and subsequent commercialization of optical fibers world wide. Corning Glass Works and AT&T are the subjects of the first two case studies of technological change (in McCormack, 1987). One company from each of the other three groups were chosen for further discussion and the emergence of optical fibers at Times Wire and Cable, Galileo and SpecTran form three further case studies (in McCormack, 1987).

In terms of a typology of technological discontinuities, optical fibers would be described by both Utterback and Kim and by Tushman and Anderson as a radical change which is competence destroying. The closest category in the Utterback and Kim framework would be that of product-process discontinuity, because the product was introduced by an industry outsider, Corning, and existing processes for the manufacture of copper conductors could not be used for the production of silica based fibers.

Optical Fibers: The Discontinuity

Figure 1

Performance of Coaxial and Fiber Optic Systems

The first fiber systems were expensive and their performance was less than the best available coaxial system as shown in Figure 1. This figure represents information on a series of optical fiber communications systems taken from the literature and trade press of the time. Major product and process changes have stimulated the emergence of a dominant product in the form of doped silica fibers. The competence destroying nature of the discontinuity lowered entry barriers and allowed new firms such as Corning, Galileo and SpecTran to enter previously impenetrable telecommunications markets.

There is little doubt that copper cable manufacturers perceived a strong product-process discontinuity with the emergence of optical fibers. Some, such as Simplex Wire and Cable and General Cable, used their cabling expertise to cable bought-in optical fiber while others, like Times Fiber Communications and Mohawk Wire and Cable, attempted to manufacture optical fibers but failed. In the case of Times Fiber Communications, (described in McCormack, 1987) it was clear that this competence destroying discontinuity was highly visible to the company's senior management, and their strategy was to acquire the technology by merging with an existing fiber optics company. Although Times Fiber Communications spent large amounts on research and development, they were unable to emerge as strong contenders in the fiber optic market for the reasons of lack of focus in research and development, an incompatibility in the "fluid" fiber and "specific" copper industry cultures and late development of the market for optical cable television systems.

Although the telecommunications market was new to Corning, optical fibers could be considered a direct outgrowth of the work begun by Hide in the 1940's (as noted in McCormack, 1987). The vapor phase deposition of silica optical fibers was a major step in a series of incremental changes at Corning Glass Works. To a large extent, Corning did not perceive a major competence destroying discontinuity, and in terms of the Utterback and Kim framework, Corning best fits the product-discontinuity description. The fact that vapor-phase technology could be transferred from earlier work at Corning Glass Works means that the discontinuity could be described as competence-enhancing. This fact is borne out by the observation that Corning holds all of the major patents for doped silica glass optical fibers. The discontinuity was seen to be in the market since Corning was an outsider to the telecommunications market. To lessen the impact of this market discontinuity, Corning embraced its tried and tested strategy of obtaining development partners and starting joint ventures. Clearly competitive strategy has an important role to play in mastering technological changes.

At AT&T, the seeds of optical communications had been sown long before the introduction of the laser in 1960, and competence enhancing changes can be seen in the progression from copper wires to optical fiber systems. Because of the truly massive scale of research and development at Bell Labs, Corning's announcement of low loss fiber in 1970 caused excitement at AT&T but certainly not despondency. No-one thought that an outsider could usurp the technological lead of the monopolistic Bell Empire. In order to climb the "vapor phase technology curve", Bell Labs transferred knowledge from its work in semiconductor fabrication to its research into fiber optic fabrication processes. The emergence of Modified Chemical Vapor Deposition was the result of a series of competence enhancing discoveries. Although the production of the glass fiber itself could be considered more of a discontinuity than events which occurred at Corning, the product, communications fiber was not, because the waveguide transmission properties of the resultant fibers were largely understood by Bell Labs as a result of previous

theoretical work. Therefore, although a discontinuity did occur, the technical strength of AT&T smoothed over any shock to the system and AT&T, with some help from the Federal Communications Commission, emerged a strong contender in optical communication systems.

At Galileo, which was an established producer of medium-high loss glass optical fibers for illumination and Cathode Ray Tube face plates, the discontinuity appears to have occurred more in its market instead of in its technology. It licensed compound glass technologies for fiber fabrication, and was also producing fibers by vapor phase deposition techniques (Porter, 1983). The move to telecommunications applications should have been complete when Galileo acquired the Wire and Cable business of the Revere Corporation of America in September of 1977. At this point, Galileo could produce fiber (by several different techniques), fiber cable, sources, detectors and auxiliary equipment. It is tempting to suggest that Galileo, like Times Fiber Communications, was "spread-too-thin" with regard to research and development effort, because even though they had fifty research and development staff many avenues of work were being investigated. At a time of rapid technological developments on all fronts, players who intended to keep ahead in all aspects of optical communications needed considerable resources. Little information is available on the vapor phase technology used by Galite to produce optical fibers or its position with respect to the Corning patents. In any event, this combination of new fabrication technologies and new markets was never pursued by Galileo and they sold the fiber optics activity to Pirelli Wire.

When Galite, the fiber manufacturing part of Galileo, was sold to Pirelli, three employees from Galileo left and started SpecTran. Their new focus was clear. They would concentrate on the manufacture of fibers. SpecTran's existence was based on the competence-destroying nature of the fiber optics transition, because it allowed SpecTran to enter a telecommunications market

which had been the sole preserve of "metal" equipment producers. The entry barriers being erected by Corning and Bell Labs were maintained when SpecTran licensed both Corning and Bell labs technology for their manufacturing processes (SpecTran, 1986). SpecTran's unique strategic move was to become a specialty supplier of fiber producing a range of fibers which transmit from the ultra violet to the infra red. SpecTran appeared to be doing well with this strategy (sales 1983 were \$1.7m; 1984 were \$6.4m (SpecTran, 1984)) although to concentrate on a niche market is considered to be a weak strategy (Abernathy and Clark, 1985, p.3).

A "Richer" Model of Discontinuities

By looking in detail at the five case studies of potential optical fiber manufacturers it was demonstrated above that each of these industry participants did not perceive the same type of discontinuity. Using the Utterback and Kim typologies, Corning, the industry outsider went through what was primarily a "product discontinuity." Although novel, the process technology could be considered as an outgrowth of previous work. Its uniquely strong patent position supports this proposition. A combination of strong research and development, patents, careful marketing and planning enabled Corning to produce a highly successful innovation in fiber optics.

AT&T perceived more of a "process discontinuity" with the emergence of fiber optics because, although Bell Labs was conversant with vapor phase technology for semiconductor manufacture, significant advances needed to be made before modified chemical vapor deposition was conceived. On the other hand the product, doped silica fiber optics, was less of a discontinuity because Bell Labs already produced compound glass optical fibers and had significant expertise in waveguide transmission.

Because Galileo was not in the telecommunications business and when it entered it concentrated in compound glass manufacturing techniques, the emergence of doped silica optical fibers was seen as a product-process discontinuity with the market, rather than the product, being more unfamiliar than the process technology.

The only company to suffer a major product-process discontinuity was Times Wire and Cable who were unfamiliar with optical waveguides and had no expertise at all in their method of manufacture. Although the company made a determined effort to acquire the new technology, they were confronted by a slowly developing market for fiber optics in cable television, diluted research and development effort, incompatibility of fiber and copper "cultures" and a lack of perseverance in top management.

SpecTran entered the business as a result of the discontinuity and developed what Abernathy and Utterback (1980) would call a "weak strategic position" by limiting itself to a niche market. With the recent slowing down of optical fiber sales in the primary market of long haul telecommunications it clearly risks direct competition from the two larger volume, lower cost producers.

Figure 2

Positions of Significant Events in the Development of Optical Fibers

Conclusions

The conclusion of the above discussion is that the model of a company defending itself against an attacker's new technology is too simplistic. There are clearly gradations in the levels of product and process discontinuities perceived by different industry participants. Figure 2 shows an attempt to place the four companies into a product/process discontinuity matrix. The obvious result shown in Figure 2 is that with hindsight it is clear that the firms on the

lower product/process "efficiency frontier" will have stronger technological positions than those farther out.

As a final comment on the models and fiber optics the significant dates of entry into the "fiber optics discontinuity" are also given on Figure 2. Although the sample is small it does seem logical that, given the emergence of a discontinuity, events which surround the companies who perceive the smaller discontinuities should occur first. They will be "first movers". Events associated with companies seeing a larger discontinuity will occur later ("second movers"). Given this, together with the documented shift in research emphasis into novel fabrication techniques, it could be expected that the next event in this emerging industry would occur further out on the efficient frontier. A radical process which will enable the product, fiber optics, to enter totally new markets is predicted - a process-product discontinuity.

Fiber optics is a non-assembled product which has emerged extremely rapidly with the introduction of the vapor phase processing technology. The lifecycle-based model of Abernathy and Utterback can be used to explain the evolution of the fiber optics industry and the implications of the model are applicable to the management of fiber optic technology.

The model's prescriptive character is consistent with the strategic moves a company makes in order to improve its competitive advantage. Technology and company strategy are interlinked not just during industry evolution, they are tightly bound during technological discontinuities as well.

Technological discontinuities are discussed in the literature in terms of two participants, an attacker and defender. We have seen here that in the case of fiber optics, several different industry participants perceive the discontinuity in different ways. Within the discontinuity, the timing of the entrance of different players can be predicted based on the size of the discontinuity they perceive.

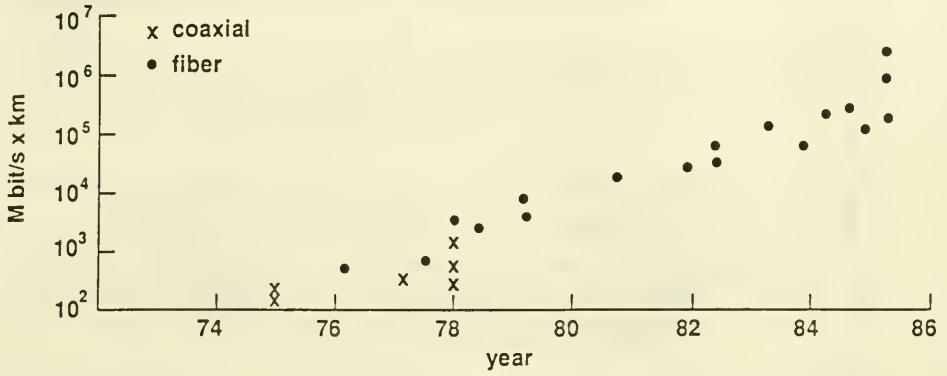
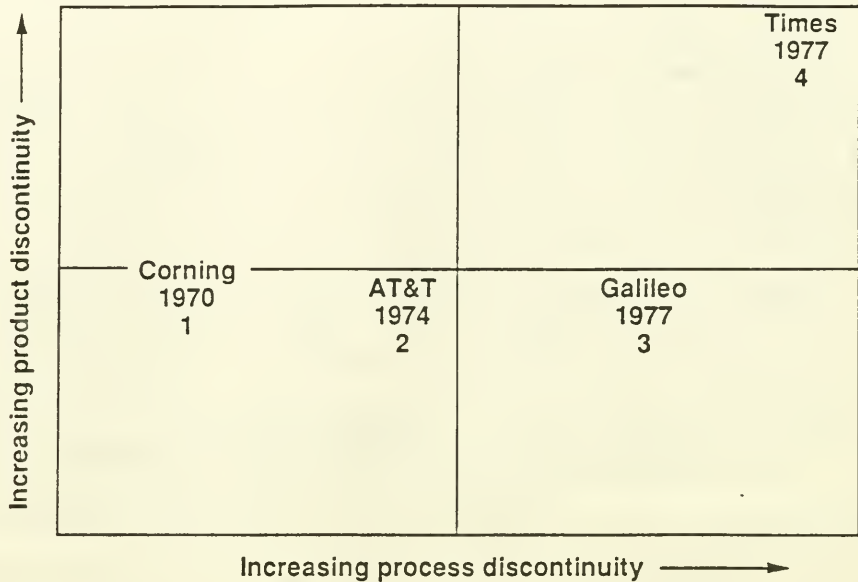


Figure 1
Performance of Coaxial and Fiber Optic Systems



- 1970: Corning produces the world's first sub 20dB/km fiber using vapor phase deposition.
- 1974: AT&T Bell Labs develops Modified Chemical Vapor Deposition (MCVD) to produce low loss fibers.
- 1977: Galileo acquires Revere Corp of America (Cables) and forms Galite, its fiber production facility.
- 1977: Times Wire and Cable and Fiber Communications Inc merge to form TFC.

Figure 2
Positions of Significant Events in the
Development of Optical Fibers

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