Techno-Paradigm Shift and its Research Methodology

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Abstract

In order to express the radical changes in the way technology has been and continues to be developed, applied, and commercialized over time, the concept of a techno-paradigm shift is used. The techno-paradigm shift is distinguished into five dimensions: business diversification, R&D competition, product development, innovation pattern, and societal diffusion of technology. In order to obtain a comprehensive understanding of these dynamic characteristics of technology, we have to orchestrate a unique blends of scholarly tools - case studies, formal modeling, and insightful observations.

Introduction

For some time, experts have been pointing out changes in the basic pattern of technology innovation (Freeman 1987). With the emergence of new high-tech industries, major changes are occurring in both corporate and government policies. These changes merit the label "paradigm shift" because they are everywhere, and they are so profound that they may make conventional wisdom in business administration, economics, and international relations obsolete. And they are all taking place simultaneously, not in isolation from each other.

From my studies in past ten years which have tried to codify the Japanese experiences with high technologies, I can characterize the dynamic nature of high technologies by five dimensions (Kodama 1995). In this paper, therefore, I will first describe my dynamic characterization of high technologies. Second I will discuss issues related to methodologies which can accommodate these techno-paradigm shifts.

Dynamic Characterization of Technology

***Continuity* in Business Diversification:** The conventional paradigm for diversification is that the development of a generic technology automatically brings diversification by applying the technology to various kinds of products. In this view, a technology is developed first for a technologically demanding, high-end product, then extended for the use of less technologically demanding, low-end products through the development of low-cost, quality-controlled mass-production processes. According to this view, diversification is based on the "spin-off" principle.

One of the most conspicuous elements of high-tech development, however, has been the codevelopment of product and process technologies. The development of a product is conducted in parallel with the development of its production technology. According to this view, without opportunities to accumulate production experience, high-tech development is not possible. This implies that business diversification in high-tech industries should follow a trajectory almost opposite to the trajectory based on the spin-off principle. Following this new trajectory, a localized technical knowledge is developed and applied to less demanding, low-end markets first. The first Toray's carbon fiber, for example, was marketed for the shaft of a golf club. As the technology was matured, the development trickled up into the high-end market, airplane's tail wings. Thus, diversification based on high technologies follows the "trickle up" process (Branscomb 1989).

***Heterogeneity* in R&D Competition:** The conventional theory of R&D competition is based on the principle of dominant design, which was originally developed to explain the automotive industry (Utterback 1975).

According to this theory, when a new technology arises there is considerable uncertainty over which of the possible variants will succeed. After a period of time and competition, however, one or a few of the variants come to dominate the others. This dominant design enforces standardization so that production or other complementary economies can be sought. Effective competition then takes place on the basis of cost and scale as well as of product performance.

Recent R&D competition among high-tech firms in the microelectronics industry, however, seems to be following a diverging pattern rather than the converging pattern implied by the dominant-design theory. In today's technology innovation race, manufacturers introduce new products every three years, before the learning process on the technology of the preceding innovation is complete. Competition may be characterized as technology predation: new devices drive their predecessors completely out of the market within six years of introduction. With this kind of technological advance, corporate decisions on investment are not made on the basis of the rate of return. They are made according to the principle of *surf-riding*: companies have no choice but to invest in successive waves of innovation or be left behind by competitors. Investment must continue just to stay in the market (Kodama 1989).

This pattern of competition is likely to change further. While today, the competitor is usually another company within the same industrial sector, in the future the competitor may be a company in a different sector. In effect a firm may not know from which corner the next competitor will appear. Thus, high-tech companies will have to monitor not only direct competitors in their own sector but also so-called invisible enemies, firms in other industries. In short, R&D competition in the high-tech industry should be framed as interindustry competition rather than interfirm competition in a given industry.

***Nonlinearity* in Product Development:** Most description of the process of technology development have employed the pipeline metaphor: new technology emerges from the successive steps of basic research, applied research, exploratory development, engineering, and manufacturing. Another, if extreme, view of technology development states that companies compete only on the basis of existing products, not those yet to be created. In this view, companies should seek constant, incremental improvements only in their products.

In reality, neither the pipeline view nor the picture of incremental development is adequate by itself (Alic et al. 1992). Between these two extremes, is a wide range of product development processes in which some parts may be drawn from existing technical collections and some parts may be drawn from the pool of scientific knowledge. In fact, this range of processes may describe most of high-tech development.

In high-tech product development, therefore, the most important capability is the ability to convert demand from a vague set of distant wants into well-defined products, which I call *demand articulation* (Kodama 1992). Articulating demand is a two-step process: first, market data must be translated into a product concept; and second, the concept must be decomposed into a set of development projects. Through the process of demand articulation, the need for a specific technology manifests itself, and R&D efforts are targeted at developing and perfecting that technology.

The concept of demand articulation becomes even more powerful when a national technology policy is analyzed. The development of the integrated circuit (IC), first in the U.S. defense sector and then in Japanese government-sponsored research consortia, best illustrates demand articulation at the national level. In the early development of IC technology, the U.S. government articulated and defined the problem to which the innovation should be addressed and supported promising aspirants in the development of that technology (OECD 1977).

Many companies in different industries were involved in bringing the integrated circuit from the defense sector into consumer-products market. In Japan, the government played a significant role in this transition by organizing a research association for very large scale integration (VLSI) development. When first formed, the association included all of Japan's major IC chip manufacturers, who then articulated their demand for manufacturing equipment and materials for chip-making. In this way, an internationally competitive infrastructure was established (Oshima 1988). This suggests that national policy can be discussed better using the concept of a "national system of demand articulation" rather than the oft-cited concept of a national system of innovation (Nelson 1993).

***Complementarity* in Innovation Patterns:** For years it has been said that innovation is achieved by breaking through the boundaries of existing technology. Recent innovations in mechatronics and optoelectronics, however, make it more appropriate to view innovation as the fusion of different types of technology rather than as a series of technical breakthroughs. Fusion means more than a combination of different technologies; it invokes an arithmetic in which one plus one makes three (Kodama 1992).

A number of revealing contrasts can be made between innovations achieved through fusion and those achieved through breakthroughs. First, while technical breakthroughs become possible when a prominent corporation in a specific industry takes a leadership role, fusion is made possible by joint operations among related industries. The mechatronics revolution in Japanese machine tools became possible through cooperation between Fanuc, a spin-off of a communications equipment manufacturer and developer of the controller, NSK, the bearing company that developed the perfect pitch ball screw, and a materials company that developed the teflon material used to coat the sliding bed. Second, while breakthrough innovations bring rapid growth for a particular corporation, fusion contributes to gradual growth in all the industries involved. Third, while breakthroughs are often associated with defense policies, fusion is promoted through industrial policy.

***Externality* in Societal Diffusion:** The conventional model of societal diffusion is formulated around information-spreading mechanisms based on personal contacts. Although a technical adjustment process is sometimes built in the model, the diffusion pattern is viewed as epidemic in the sense of learning by infection; thus, its time-path follows the logistic curve.

The development of high technologies, however, is changing this pattern of diffusion and suggests that we need to look for signs of *institutional evolution* rather than for sign of a technical adjustment process. The diffusion of CAT (computerized axial tomography) scanners is a prime example of the relevancy of technology to social institutions accelerating rather than discouraging acceptance. Lobbying by a professional association of CAT experts brought about the government's decision to cover the use of scanners in its national health insurance plan.

A characteristic of information technology is its *network externality* (David 1986). Integration, however, requires some measure of technical standardization. In other words, the widespread diffusion of information technology requires the coevolution of technology and social institutions.

A study based on Japan's unique database that tracks the installation of computers by forty-seven prefectural governments every year since 1963 reveals that the diffusion of computer utilization is in fact a function of organizational change rather than technical sophistication. Furthermore, diffusion occurs more rapidly when the computers are used for new activities, indicating that the institutional framework for new activities coevolves with the diffusion of the new technology (Kodama 1990).

Blending Analytical Tools

Roughly speaking, there are two methodologies used in studying technological innovation: one is the case study; the other a formal modeling analysis. Both methods seem to have intrinsic deficiencies.

A case study may generate insight and the insight can be surprising, but the findings are usually specific to the object and the environment of the case study. Policy implications can be drawn only through analogy. By comparing several cases, it may be possible to structure past experiences and thus learn important lessons, but, if the whole paradigm is changing, past experiences will be of little use to decision makers, who are primarily interested in the future.

Moreover, case study data are collected through interviews with the people who developed the technology, but in many cases, engineers cannot relate the bounded rationality behind their decisions. They might have done something very innovative that they themselves are not aware of. This is especially true when paradigms are shifting. Usually, it is difficult for people to recognize their innovative accomplishments.

A formal model does allow us to generalize about past experiences, but technology is specific in every aspect even though science is universal. Therefore, there is always the risk of overgeneralization in a formal model. Technologists understandably complain about this approach, saying that it is difficult to identify what kinds of technologies model builders are talking about.

Furthermore, a formal model requires a rigid conceptual framework. Such a framework is often derived from past observable phenomena. Although established frameworks are the most appropriate for analyzing past technologies, when a new paradigm of technology emerges, there may be a serious discrepancy between the subject of study and the methodology used for the study. To study a new paradigm, we have to create a new conceptual framework.

The individual wishing to study technological innovation may feel trapped between a rock and a hard place: case study without generalization is only storytelling, but a generalized approach without specific cases is not a study of technology. We have to strike a balance between these two conflicting approaches. This balance can be attained by taking a new approach to both case studies and formal models, but, it would be effectively realized by bringing formal models closer to case studies.

The management science approach stemmed from the success in operations research during the World War II, but when it comes to management of technology, the approach has an intrinsic deficiency. *First*, managerial decisions about technology development are decisions at strategic levels, not operational decisions. These types of decisions must be made in highly unstructured environments (Kodama 1970). *Second*, the process of developing a technology is not repeatable, because it is always a creative thought that leads to a business success. *Third*, there is no golden formula to follow for technology development. On an abstract level, the discounted-cash flow method may be applied to managing technology development, but in applying such a formula, it is often more crucial to estimate parameters rather than to make a precise calculation because the process of innovation is characterized by a high degree of uncertainty and unpredictability.

Last, but not the least, management science has failed to offer science policy administrators and research managers a vocabulary and a framework for talking about the choices they must make. Key concept for these decision makers is often derived from an in-depth and sometimes naive study of technology rather than from an attempt to apply general management principles and mathematics to technology management.

Therefore, we should be modest in talking about the management of technology. All that we can reasonably do is to provide an acceptable explanation about why and how some of existing practices have proved effective. In other words, using each dimension of techno-paradigm shift as a framework of appreciation, we can conduct what Nelson called an "appreciative theorizing" of successful business practices (Nelson 1982). By doing so, we can at least put managers in better positions to invent new management approaches to the changing business environments in which high technology is going to play a pivotal role.

In conclusion, for the study of the management of technology, I do believe that we should join three components of technology management analysis: case studies, formal modeling analysis, and appreciative theorizing.

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