＜論　　説＞

Two Dysfunctions in High-Tech R&D

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Abstract

In this paper, I will discuss about the organisational problems in the field of research and development of high technology in a firm. In particular, two dysfunctional phenomena are very important because they pose peculiar problems in R&D activities.

The first problem is *Reverse Hierarchy* wherein the scientific knowledge hierarchy expands in direction that is reverse to that of the power hierarchy. In high-tech industries, the forefront knowledge is centralised to young scientists who hold little power with regard to investment decision-making. On the contrary, top managers of the firm who are located at the top of the power hierarchy usually cannot comprehend forefront scientific knowledge.

The second problem is the *Paradox of Conservatism by Innovation*, which means that successful technological innovation cases the members of the firm to resist further innovation involving radical change in the fundamental structure of core technology. In other words, members of the organisation are inclined to make only a small improvement in technological innovation. Greater the success, the stronger or longer is the conservatism.

A method to resolve the first problem is to designate senior scientists for positions in the top management. As they are more familiar with science than the business managers are, they can understand forefront scientific knowledge to a certain extent. However, they are inclined to be attached to past innovation that was devised by them. Thus, the second problem arises from the solution for the first problem.

I investigate how to resolve these problems through Japanese case studies. Japanese companies try to resolve the first problem of Reverse Hierarchy by two major methods. The first one is to expand the discretion of scientists. The second method involves utilizing middle managers as mediators between the top business managers and the young scientists.

The second problem of the Paradox of Conservatism by Innovation can be resolved by a method of organization development that involves educating the company members about the na-

ture of technological change in the modern innovation era.

1. Technological Hierarchy

Technological Hierarchy starts from fundamental scientific knowledge that can be expanded to various stages of application. Finally, it will be realized as some practical products or processes, which from the last stage of the Technological Hierarchy. Technological Hierarchy is a hierarchy of technological problems and solutions. Some technological problems will arise in any application. Although there are some solutions for the application problems, every specific solution method will lead to particular sub-problems.

For example, a metal friction problem may be resolved by using a lubricating oil or by high-grade flatten processing of mechanical parts. The first method will lead to the problem of how to dispose the ashes of the oil. Similarly, the high-grade flattening method will cause the next problem of how to develop advanced flattening technology.

Fundamental scientific knowledge can reach the final stage of practical products or processes through several application stages that involve applied research and development. Various stages constitute the chain of problems and solutions.

Technological Hierarchy is suggested by the Design Hierarchy that was proposed by W. J. Abernathy[1)]. He devised the Design Hierarchy by the analysis of the automobile industry. The Design Hierarchy starts from the core concept, which was named by Abernathy, it refers to the core technological function. In the nineteenth century, the automobile industry followed three core concepts, namely, the steam engine system, electric engine system and gasoline internal-combustion engine system. Each of these core concepts was developed into a practical automobile through various application processes that resolved numerous subsidiary problems.

Although Abarnathy's Design Hierarchy is also a hierarchy of problems and resolving methods in the development process, this concept differs from the Technological Hierarchy in two aspects. Firstly, Technological Hierarchy is a concept of ex ante, whereas Design Hierarchy is a concept of ex post. Design Hierarchy is developed from the analysis of the history of automobile development. However, Technological Hierarchy is developed from a strategic concept that is a prospect of possible development of fundamental scientific knowledge.

Secondly, Technological Hierarchy starts from fundamental knowledge of science, whereas Design Hierarchy starts from a concrete mechanical function. Therefore, Design Hierarchy mainly involves the development stage of technology, where engineering problems are more important than scientific problems. On the other hand, Technological Hierarchy involves all of the stages of research and development, which include fundamental research and applied research of

science as well as the engineering development stage.

Therefore, Technological Hierarchy is a hierarchy of scientific and engineering knowledge. Forefront scientific knowledge is located at the starting point of the knowledge hierarchy. Moreover, it is the most fundamental starting point of technology.

2. Reverse Hierarchy Problem

Technological Hierarchy is developed for the resolution of scientific or technological problems, by two different methods. The first one is scientific motivation which is exhibited by the scientists. The second one is marketability, which is sought by business managers.

In the first case, scientists construct their research strategy, which is led by their own scientific interest following the logic of natural science. Almost pure fundamental research works are directed by scientific interest or motivation, for example, the investigation into some mysterious phenomena. These investigations may lead to a brilliant discovery that could sow the seeds of technological break-through.

The second case concerns the requests for improved technology made by business managers for relevant business issues such as the market share, profitability, and the growth rate of the market. For example, if cost reduction, miniaturization or lightening of some materials realizes a large market, the business operations department requests for these improvements to the R&D department.

The first method of progressing R&D, which may sow the seeds of technological development, is called technology push innovation, and the second way of proceeding R&D is called needs pull innovation. These two methods of requests for R&D are based on very different perspectives one is based on science, whereas the other is based on business. These two different ways must be combined in order to achieve technological innovation in a business organization[2)].

While power hierarchy of an organization can manage the needs pull innovation relatively well, it cannot manage the seeds push innovation efficiently because of the Reverse Hierarchy problem.

As previously mentioned, the starting point of the technological hierarchy is fundamental scientific knowledge, which forms the most critical data for devising the R&D strategy. However, forefront scientific knowledge, which is specialized information, is directed toward young scientists who have little discretion with regard to strategic decision-making.

On the other hand, business top managers who have the highest authority to devise the corporate strategy usually cannot understand forefront scientific knowledge that forms the crucial information required developing the strategy. This is the essence of the Reverse Hierarchy prob-

lem.

A normal power hierarchy can resolve ordinary problems. Most trivial matters related to such problems may not be critical. However, their accumulative effect can be a serious concern for the organisation as a whole. In some marketing problems, for example, top managers need not know of any detailed sales data of an extremely specific field. Such specific and trivial detailed data lead to bias in general decision-making, because very specific area may not be regarded as very important.

The pyramidal power hierarchy is the device to promote general decision-making by eliminating or summarizing the detailed data in bottom-up information transmitting. This kind of information system can manage the ordinary organisational behaviour as discussed above.

However, in R&D processes extremely specific scientific knowledge has a very crucial effect on the entire structure of innovation. Particularly, in the case of technology push innovation, forefront scientific knowledge, which usually requires very deep and specific expertise for its comprehension, is a critical factor for devising the innovation strategy at the starting point.

Although top business managers can understand the marketable value of new products or processes that are at the bottom of the Technological Hierarchy, they rely on young scientists in devising the innovation strategy because of their ignorance with regard to forefront scientific knowledge. Senior researchers as middle managers can understand the scientific significance of forefront knowledge to a certain extent.

Thus, Reverse Hierarchy is the phenomenon in high-tech companies of the reverse expansion of the technological knowledge hierarchy with respect to the power hierarchy.

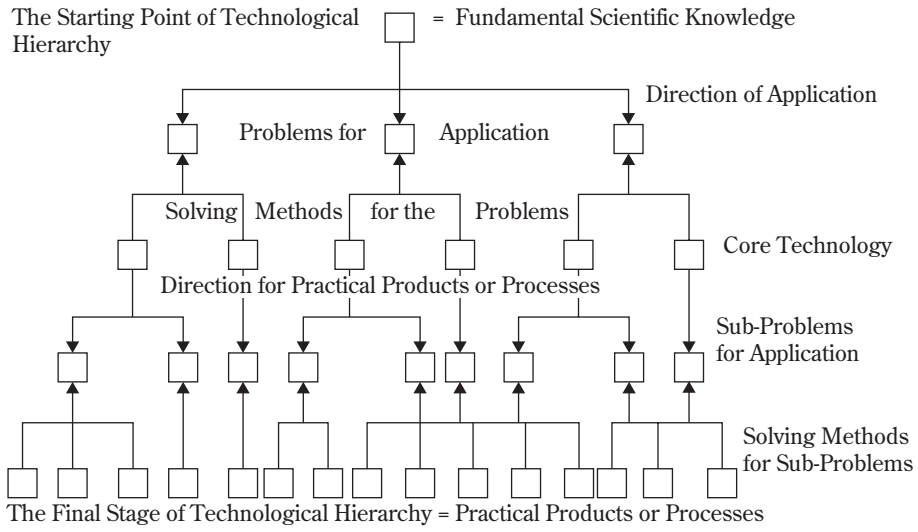

Figure 1. Technological Hierarchy

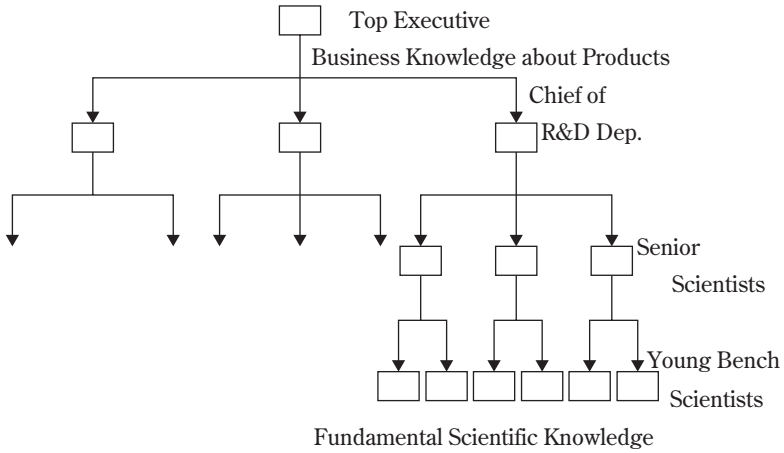

Figure 2. Power Hierarchy

3. Paradox of Conservatism by Innovation

Generally, the progress of technological innovation has a cumulative effect in that previously developed technology improves the current technological development, which in turn, will accelerate future technological development. Thus, technological innovation stimulates further innovation.

However, from the perspective of a private enterprise, the pioneering companies constantly change. For example, the front runners in the field of semiconductors, computers, cameras, sewing machines and automobiles usually change. Once a company achieves success from some technological innovation, it ought to have a technological advantage over other competitors. Then, what could be the reason behind the changing pioneer phenomenon?

(1) Economic Factors

According to the Technological Hierarchy, innovated new core technology has a large possibility for application. At the beginning stage of the life cycle of new core technology, applicable technology plays a very important role in improving the practicability of the new core technology. Moreover, in an early stage of the product life cycle, simple improvement would substantially advance the marketability of the new products[3]. Since the cost performance of this technological improvement is very efficient, such a simple improvement is likely to be maintained in the business organisation for a long period.

At the maturity stage of the product life cycle, simple improvement cannot lead to high performance. The cost performance of improvement technology declines as the product life cycle proceeds. If the company still relies on simple improvement, the resultant innovation will lead to

conservatism.

Furthermore, attachment for existing equipment is the cause of conservatism. Abernathy pointed out the problem that Ford Motor Company avoided a drastic technological innovation because of its desire to maintain existing equipment after Model T diffused in the 1920s[4]. As a radical technological innovation results in a drastic change for the existing equipment, it leads to tremendous sunk costs. This is another economic factor that causes conservatism by successful innovation.

（2）Organisational Factors

Organisational factors of Conservatism by Innovation may arise from a solution for Reverse Hierarchy. They involve the emotional attachment of top managers in science or engineering for past successful innovation that was achieved by them. Such attachment is usually combined with their social prestige in the company[5].

Top corporate managers who have established a career in science or engineering can resolve the Reverse Hierarchy to a certain extent because they can understand the scientific or engineering information by their education and training, notwithstanding their limited acquaintance with forefront science. Nowadays, instances of engineers as presidents or scientists as vice-presidents are actually increasing in high-tech companies.

However, scientists or engineers in the top management may lead to the other dysfunction of Conservatism by Innovation. Even if they are not attached to past innovation led by them, other members of the management may be liable to feel hesitant or nervous to challenge a recent innovation that may make a significant past innovation obsolete. Past successful innovations may have led to the promotion of distinguished scientists or engineers to top executives positions of the firm. Therefore, from the perspective of the members of the firm, challenging a recent innovation means challenging the top executives.

For example, Sony which was the pioneer of the transistor radio lagged behind its competition in the field of integrated circuits. Since the two prominent entrepreneurs who founded Sony, S. Ifuka and A. Morita were both scientific engineers, the decline of a recent innovation may be attributed to this organisational factor.

4. Case Studies of Japanese Companies

The two dysfunctional phenomena mentioned above were identified mainly in high-tech Japanese companies. We can obtain some effective solutions for these dysfunctions by futher investigating these high-tech companies.

(1) How to Cope with the Reverse Hierarchy

The various resolving methods for Reverse Hierarchy by high-tech Japanese companies are roughly grouped into two major methods. The first method involves expanding the discretion of corporate scientists. The second one involves creating an organisational device that can mediate between the scientific or engineering side and the business management side. In this organisational device, senior scientists as middle managers play a very important role.

With regard to the first method, North Star Research by Hitachi corporation and Under the Table Research by Toshiba, Fuji Electric Research Centre and Sumitomo Electric Engineering Research Centre are almost the same systems because they involve expanding the discretion of scientists by allowing them to pursue voluntary research in a field of their choice, apart from their obligated research. Voluntary research is limited to 10% of the total research resources at any company.

The second method, involves various seeds proposing systems and meeting systems that act as crucial opportunities for discussion between scientists and business managers, and thus, they lead to effective communication. These interactive systems involve young scientists, senior scientists, business managers and top executives. Moreover, internal corporate venture and project teams are actively created at most high-tech companies such as Hitachi, Toshiba, NEC (Nippon Electric Company), and Panasonic.

Middle managers such as senior scientists make business requests to young scientists in the 'scientific language'as well as communicate the views of the forefront young scientists to the top business managers in the 'business language'. Thus, they act as translators of the languages of science and business, and as coordinators between the scientists and the business managers.

The importance of this function of middle managers as coordinators who have both, a scientific or engineering career and management experience, is also emphasized by European social scientists like R. A. Burgelman and L. R. Sayles[6] and I. Wagner[7].

(2) How to Cope with the Conservatism by Innovation

Economic factors causing conservatism of past innovation include existing high productivity that has been realized by cumulative improvement. Abernathy presented a dilemma between innovation and productivity[8]. In the maturity stage of the product life cycle, since past innovation has substantially improved, the productivity has increased considerably. The increased productivity is realized by high and wide standardization of all of the product parts and manufacturing processes. High profitability caused by such high productivity, combined with the motivation to avoid sunk costs due to the radical changing of existing equipments, leads to conservatism.

However, once the environment changes radically, the existing equipment can efficiently produce only obsolete products. Roughly speaking, the problem faced by U.S. automobile companies after the oil crisis in the 1970s is an example of this phenomenon. Even the promotional efforts for radical innovation proposed by Abarnathy, Clark and Kantrow, could not resolve the dilemma faced by the U.S. automobile-industry[9].

K. B. Clark and T. Fujimoto suggested that highly integrated teams with active mutual communication that are led by influential product managers or project managers in the automobile company achieved effective adaptation to an environmental change[10].

The means to cope with the organisational factors of conservatism involve two methods. The first one is organisation development（O.D.）, which means raising awareness among the members of the organisation. The second one involves championing activities for the members that lead innovation in the organisation.

In the first method, the main purpose of O.D. at resolving the Paradox of Conservatism by Innovation is to change the mind-set of the members towards the identification of innovation and the innovator. Nowadays, any recent innovation rapidly becomes obsolete. If the members of the organisation identify a successful technological innovation and the innovator who was promoted to a technological executive position by his own technological success, the innovator is liable to resist a recent innovation that makes the previous innovation obsolete, so as to prevent his/her knowledge from being considered outdated. Since a senior executive of the previous successful innovator exerts greater persuasive power and influence in the organisation, the resistance against recent innovation can pose serious problem.

Although an initiative from the top management is the most important factor for effective O. D., external experts can accomplish the actual education or coordination of the members of the organisation[11]. In sum, creating a good-will for innovations in the organisation is the essence of O.D. in order to solve the problem of conservatism[12].

The second method to cope with the Paradox involves conducting championing activities. This refers to supporting and encouraging the members that lead innovation to present their unique idea or protecting them from the resistant power against their innovative ideas. Burgelman and Sayles emphasized the role of the two types of champions. The first one is a product champion who supports innovative members from the scientific or engineering department, and the second one is an organisational champion who coordinates the interactions between innovative members and top business executives[13].

5. Some Implications

The dysfunction of the Reverse Hierarchy may occur in a case where specific data has far more crucial implications for an organisation as a whole than other data, for example, in critical operations for emergencies such as fire fighting and battle activity. This dysfunction challenges the pyramidal power hierarchy by posing the problem of disharmony between the organisational device and the confronted problem.

For the case mentioned above, some special organisational devices that expand the discretion of field operators or create a facility of hot-lines for top executives must be developed.

Moreover, the meditative function of middle management and projective organisation must be useful in resolving the dysfunction. The utility of these organisational devices can be confirmed in an actual case of technological innovation.

Conservatism by Innovation could also arise from innovation in fields apart from technology, for example, in marketing or other managerial areas. In both of organisational and personal affairs, successful innovative behaviour that is likely to be repeated eventually becomes a programmed behaviour. Thus, this programming tendency is the cause of conservatism, irrespective of the increase in efficiency resulting from the programmed decision.

In spite of the challenge posed by environmental change, it is difficult to eliminate conservatism before a resultant catastrophe because of the efficiency caused by programmed behaviour. However, instances of innovating firms in high-tech industries indicate that changing the mindset of members of the organisation is effective in leading to their acceptance of radical ideas before an impending catastrophe.

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