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TWO DYSFUNCTIONS IN HIGH-TECH RESEARCH AND DEVELOPMENT

Kazunobu Oyama

Professor of the Faculty of Economics
Kanagawa University

In this paper, I discuss organizational problems in the field of high-tech research and development in a firm. In particular, two dysfunctional phenomena are very important because they pose peculiar problems in Research and Development activities.

The first problem is reverse hierarchy wherein the scientific knowledge hierarchy expands in a direction that is reverse to that of the power hierarchy. In high-tech industries, forefront knowledge is concentrated in junior scientists who hold little power with regard to investment decision-making. On the other hand, 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 causes 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 organization are inclined to make only small improvements in technological innovation. The greater the success, the stronger and longer lasting is the conservatism.

A way to resolve the first problem is to designate senior scientists for positions in top management. As they are more familiar with science than business managers, they can understand forefront scientific knowledge to a certain extent. However, they tend to cling to past innovations that they themselves have devised. Thus, a second problem arises from the solution for the first.

I analyse potential solutions to these problems through Japanese case studies. Japanese companies try to resolve the first problem, that of reverse hierarchy, in two major ways. 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 junior scientists.

Kazunobu Oyama – Kanagavos universiteto Ekonomikos fakulteto profesorius. Kanagawa University, Faculty of Economics, Professor.
el. paštas / e-mail: oyamak01@kanagawa-u.ac.jp

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The second problem, the paradox of conservatism by innovation can be resolved through organizational development that involves educating company members on the nature of technological change in the modern era of innovation.

Keywords: *Reverse Hierarchy, Paradox of Conservatism by Innovation, Economic Factors, Organizational Factors, Case Studies.*

Raktažodžiai: *reversyvi hierarchija, sąstingio inovacija paradoksas, ekonominiai faktoriai, organizaciniai faktoriai, atvejų analizė.*

1. Technological hierarchy

The basis of *technological hierarchy* is fundamental scientific knowledge that can be expanded to various stages of application. Eventually, this knowledge can be implemented in practical products or processes, which constitutes the final stage of a technological hierarchy. Technological hierarchy is a hierarchy of technological problems and solutions. Some technological problems may arise in any application. Although there are some solutions to application problems, every specific solution may lead to particular sub-problems.

For example, a metal friction problem may be resolved by using lubricating oil or by high-grade polishing of mechanical parts. The first solution will lead to the problem of how to dispose of the oil soot. Similarly, the solution of high-grade polishing will result in the problem of how to develop advanced polishing technology.

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

The construct of technological hierarchy may be derived from the idea of *design hierarchy* proposed by W.J. Abernathy.[1] He devised the concept of design hierarchy based on an analysis of the automotive industry. The core concept of design hierarchy, as defined by Abernathy, refers to the core technological function. In the nineteenth century, the automotive industry pursued three core concepts, namely, the steam engine system, the electric engine system, and the 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 Abernathy's design hierarchy is also a hierarchy of problems and resolution methods in the development process, this concept differs from technological hierarchy in two aspects. Firstly, technological hierarchy is an ex ante concept, whereas design hierarchy is an ex post concept. Design Hierarchy is based on the analysis of the history of automobile development. On the other hand, technological hierarchy is a strategic concept based on prospects for possible development of fundamental scientific knowledge.

Secondly, technological hierarchy is based on fundamental knowledge of science, whereas design hierarchy is based on specific mechanical function. Therefore,

design hierarchy is mainly concerned with the development stages of technology, and engineering problems are more important than scientific ones. Conversely, technological hierarchy is concerned with all stages of research and development, including fundamental research, applied scientific research, and engineering development.

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, forefront scientific knowledge is the most fundamental starting point of technology.

2. The reverse hierarchy problem

The purpose of technological hierarchy is to account for the resolution of scientific and 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 devise a research strategy inspired by their own scientific interests following the scientific method. Most pure fundamental research is guided by scientific interest and motivation, e.g. the investigation of fascinating natural phenomena. These investigations may lead to a brilliant discovery that could sow the seeds of a technological break-through.

The second case concerns requests for improved technology made by business managers for the sake of relevant business issues such as market share, profitability, and growth of the market. For example, if cost reduction, miniaturization, or weight reduction of some materials were to realize a larger market, the business operations department would request such improvements from the R&D department.

The first method of driving R&D, which may sow the seeds of technological development, is called *technology push innovation*, and the second approach of driving R&D is called *needs pull innovation*. These two methods of initiating R&D are based on very different perspectives. The first is based on science, whereas the second one is based on business. These two different approaches must be combined to achieve technological innovation in a business organization.[2]

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

As previously mentioned, the basis of technological hierarchy is fundamental scientific knowledge, which serves as the most critical data for devising R&D strategy. However, forefront scientific knowledge, which is specialized information, is more accessible to junior scientists who have little discretion with regard to strategic decision-making.

On the other hand, top business managers who have the highest authority in devising corporate strategy usually cannot understand forefront scientific knowledge that serves as the crucial information required for developing such strategy. This is the essence of the reverse hierarchy problem.

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

A pyramidal power hierarchy works to promote general decision-making by eliminating or summarizing detailed data in a bottom-up movement of information. This kind of information system is sufficient for the management of ordinary organizational behaviour as discussed above.

However, in R&D processes, extremely specific scientific knowledge has a 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 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 junior scientists in devising an 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 of reverse expansion of the technological knowledge hierarchy with respect to the power hierarchy in high-tech companies.

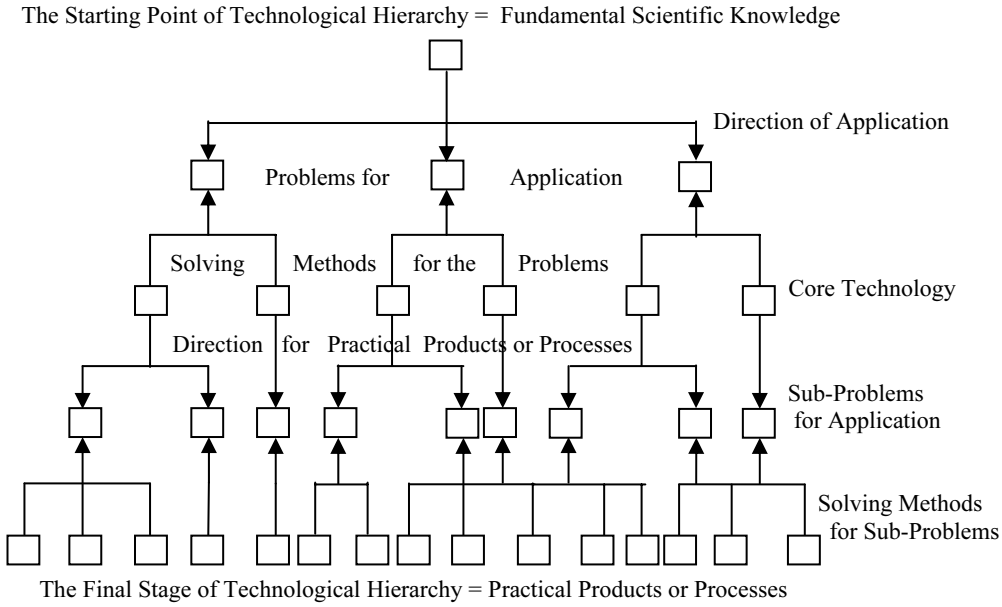

Figure 1. Technological Hierarchy

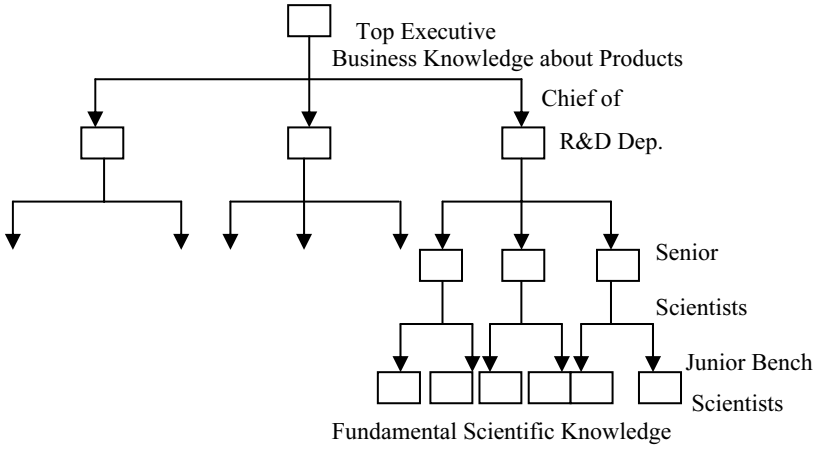

Figure 2. Power Hierarchy

3. The paradox of conservatism by innovation

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

However, from the perspective of private enterprise, companies that take on the role of a pioneer constantly rotate. For example, there are usually different companies that successively take on the role of the front-runner in the fields of semiconductors, computers, cameras, sewing machines, and automobiles. Once a company achieves success on the basis of some technological innovation, it ought to have a technological advantage over other competitors. Then, what could be the reason behind the changing pioneer phenomenon?

3.1. Economic factors

According to technological hierarchy, newly innovated core technologies have an enormous potential for application. At the initial stage of the life cycle of a 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, a simple improvement may substantially advance the marketability of the new product.[3] Since the cost performance of such technological improvement is very efficient, a simple improvement is likely to be retained in the business organization for a long period.

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

Furthermore, attachment to existing production equipment may cause conservatism. Abernathy points out that the Ford Motor Company avoided drastic technological innovation because of its desire to maintain existing manufacturing equipment after Model T diffused in the 1920s.[4] Since radical technological innovation results in drastic changes to existing equipment, it leads to tremendous sunk costs. This is another economic factor that causes conservatism because of successful innovation.

3.2. Organizational factors

Organizational factors of conservatism by innovation may arise from a solution to reverse hierarchy. Such factors usually involve the emotional attachment of top managers in science or engineering to successful innovations that they have achieved in the past. Such attachment is usually compounded by their social prestige in the company.

Top corporate managers who have established a career in science or engineering can resolve issues of reverse hierarchy to a certain extent since they can understand the scientific or engineering information because of 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, the presence of scientists or engineers in top management may lead to the dysfunction of conservatism by innovation. Even if they are not attached to past innovations of their own design, other management staff may feel hesitant or anxious about endorsing a new 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 executive positions in the firm. Therefore, from the perspective of the members of the firm, endorsing a new innovation means challenging the top executives.

For example, Sony, which had been the pioneer in the field of 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 new innovation in the company may be attributed to this organizational factor.

4. Case studies of Japanese companies

The two dysfunctional phenomena mentioned above have been identified in high-tech Japanese companies. We can infer some effective solutions for these dysfunctions by further investigating these high-tech companies.

4.1. How to cope with reverse hierarchy

The various solutions to reverse hierarchy found in high-tech Japanese companies may roughly be grouped into two major categories. The first approach involves expanding the discretion of corporate scientists. The second one involves creating an organizational device that can mediate between the scientific or engineering side and the business management side. In this organizational device, senior scientists play a very important role as middle managers.

With regard to the first method, North Star Research of the Hitachi Corporation, Under the Table Research of 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, in addition to their mandatory research. Voluntary research is limited to 10% of total research resources at these companies.

The second method involves various needs proposal systems and meeting systems that act as crucial opportunities for discussion between scientists and business managers, and thus, facilitate effective communication. These interactive systems involve junior scientists, senior scientists, business managers and top executives. Moreover, most high-tech companies such as Hitachi, Toshiba, NEC (Nippon Electric Company),[5] and Panasonic create internal corporate venture and project teams.

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

4.2. How to cope with conservatism by innovation

One economic factor that causes conservation of past innovation is the existence of high productivity achieved by cumulative improvement. Abernathy presents a dilemma between innovation and productivity.[8] In the maturity stage of the product life cycle, there is considerable productivity because of substantially improved past innovation. The increased productivity is achieved by high and wide standardization of all product parts and manufacturing processes. High profitability facilitated by such high productivity, combined with the motivation to avoid sunk costs due to radical changes to existing equipment, leads to conservatism.

However, once the business environment changes radically, existing equipment can efficiently produce only obsolete products. Roughly speaking, the problem faced by the U.S. automotive companies after the oil crisis of the 1970s is an example of this phenomenon. Even the promotional efforts for radical innovation undertaken by

Abernathy, Clark and Kantrow could not resolve the dilemma faced by the U.S. automotive industry.[9]

K. B. Clark and T. Fujimoto suggest that highly integrated teams with active mutual communication led by influential product managers or project managers have achieved effective adaptation to environmental change[10] in Japanese automotive companies.

There are two ways to cope with the organizational factors of conservatism. The first one is organization development (O.D.), which involves raising awareness among members of the organization. The second one involves championing activities for members that lead innovation in the organization.

The main purpose of O.D., the first method, is to change the mind-set of the members towards the identification of innovation and innovators. Nowadays, any new innovation rapidly becomes obsolete. If members of the organization identify a successful technological innovation and the responsible innovator is promoted to a technological executive position, the innovator is liable to resist a new innovation that makes the previous one 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 organization, resistance to new innovation can pose a serious problem.

Although initiative from top management is the most important factor in effective O.D., external experts may carry out the actual education or coordination of the members of the organization.[11] In sum, creating good will for innovators in the organization is the essence of O.D. in solving the problem of conservatism.[12]

The second method to cope with the paradox involves conducting championing activities. This refers to supporting and encouraging members that lead innovation to present their unique ideas or protecting them from powers resistant to their innovative ideas. Burgelman and Sayles emphasize the role of 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 organizational champion who coordinates interaction between innovative members and top business executives.[13]

5. Some implications

The dysfunction of reverse hierarchy may occur in cases where specific data has far more crucial implications for an organization as a whole than other data, for example, in critical emergency operations such as fire fighting or military action. This dysfunction challenges the pyramidal power hierarchy by posing the problem of disharmony between the organizational device and the confronted problem.

The case mentioned above would benefit from special organizational devices that expand the discretion of field actors or create a direct route of communication to top executives.

Moreover, the reflective function of middle management and projective organization should be useful in alleviating the dysfunction. The benefit of such organizational devices can be confirmed in actual cases 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 organizational and personal affairs, successful innovative behaviour that is likely to be repeated eventually becomes programmed behaviour. Thus, this programming tendency is the cause of conservatism, irrespective of the increase in efficiency resulting from programmed decisions.

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

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DVI AUKŠTŲJŲ TECHNOLOGIJŲ TYRIMO IR VYSYMO DISFUNKCIJOS

Kazunobu Oyama

Santrauka

Straipsnyje analizuojamos dvi pagrindinės problemos (*disfunkciniai fenomenai*)*, su kuriomis susiduriama tiriant ir vystant aukštąsias technologijas: 1*) *reversinė hierarchija ir 2*) *sąstingio inovacija paradoksas. Autorius analizuoja ekonominių ir organizacinių veiksnių įtaką šių problemų struktūrai atskleisti, pasitelkia atvejų analizę ir nurodo tris problemų sprendimo priemones: a*) *mokslininkų diskretiškumo stiprinimas, b*) *vidurinės grandies vadybininkų tarpininkavimas, c*) *organizacijos plėtra, apimanti mokymus apie technologinių pokyčių prigimtį.*