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FACTORS AFFECTING INVENTION AND INNOVATION IN SCIENCE AND TECHNOLOGY: IMPLICATIONS FOR THE PEOPLE'S REPUBLIC OF CHINA

by

Jin Xiao Yin*+

Working Paper #1691-85 August, 1985

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FACTORS AFFECTING INVENTION AND INNOVATION IN SCIENCE AND TECHNOLOGY: IMPLICATIONS FOR THE PEOPLE´S REPUBLIC OF CHINA

Jin Xiao Yin

1. Introduction

The history of mankind is one of continuous development from the realm of necessity to the realm of freedom. This process is never ending. In the fields of production and scientific experiment, mankind makes constant progress and nature undergoes constant change; they never remain at the same level. Therefore, man has constantly to sum up experience and go on discovering, inventing, innovating, creating, and advancing.

Natural science is one of man´s weapons in his fight for freedom. For the purpose of attaining freedom in the world of nature, man must use natural science to understand, conquer and change nature and thus attain freedom from nature. Usually, man conquers nature, changes nature, and attains freedom from nature through invention and innovation. With technological invention and innovation, mankind has pulled itself from the mud huts of nut and berry gatherers through the Stone, Bronze, and Iron Ages, the Industrial Revolution, and into what has been called the Atomic Age, Electronic Age, Computer Age, the Second Industrial Revolution, the Third Industrial Revolution, etc. So both invention and innovation are important weapons attaining freedom from nature, and are the important symbols of mankind´s civilization and progress.

Technological invention and innovation are the important marks measuring the level of science and technology for every country. Statistics show that developed or industrialized countries have more inventions and innovations than developing countries, because the former have higher levels of science and technology than the latter as a whole.

Technological invention and innovation also refers to the total organizational involvement leading to the profitable application of science and technology. They may provide the key to opening the "door of plenty" to even the poorest developing nation. Proper utilization of invention and innovation represents great promise for improving economic standards in developing nations. Improved economic standards should result and afford the means for a better life. A better life would include increased lifespan, relative freedom from sickness and disease, improved productivity and social contribution, and the means to acquire and enjoy material goods and services.

Technological invention and innovation are also vital for survival. They can create new industries and transform or eliminate existing ones. An analysis of business failures cited significant instances where inventors and innovators failed to translate technological creativity into profitable operation.(1-3) Invention and innovation can lead to competitive and sales advantages in a growing industry, or to diversification and new application for existing products in more mature companies.

In short, technological invention and innovation will affect national development, industrial economic development, and people´s daily life. These points have been proven by innumerable examples. The ability to develop successful inventions and innovations is crucial to the health of individual firms, industries, and to the economy as a whole; the more inventions and innovations we attain, the more profits and freedom we have.

As the rate-of-change of technology increases, as the degree of national and international competition accelerates, and as pressures increase for greater productivity, every firm, every scientific research institute, or every unit must enhance its ability to develop successful innovations, introduce and commercialize new products and processes over time.

The basic tasks of each firm or scientific research institute are to produce new scientific results (especially inventions and innovations) and train competent people (especially scientists, engineers, and entrepreneurs who are first rate by world standards). They must develop more scientific and technological achievements of high quality and train scientific and technological personnel. They must achieve more new products, more inventions and more innovations. On the one hand, during the production of scientific results many competent people are trained. On the other hand, when we train new talent we can get more achievements later. This is reciprocal process and dialectical unity. The main criterion for judging the scientific and technical work of each firm or scientific research institute should be the successful fulfillment of these basic tasks.

Now the key question is how we can stimulate and get more inventions and innovations under the given conditions? What factors will affect invention and innovation?

As we know, invention and innovation are the results of creative labor, are themselves complex mental work. During the process of invention and innovation, there are a lot of influential factors. At the same time, invention and innovation also involve highly complex decisions, including what science and technology to develop, evaluation of the state of the art, evolutionary and revolutionary change, market appraisal, production control, the national and international political and economic environment, potential risk, competition, and the immediate operational environment, specifically, organizational processes that might abet or retard the process of invention and innovation.

With so many factors and interacting considerations, there is a need to understand the definition of invention and innovation, what advantages exist in invention and innovation, how they take place, where there have been successful inventions and innovations, whether there are organizational patterns that can provide guidance for intensifying innovations in developing countries, whether certain organizational environments tend to better spawn innovations in specific areas, to what extent political or cultural factors affect invention and innovation, and how management affects the innovation process. Other interesting questions involve what internal and external environmental and operational factors serve as stimulants, or barriers, to invention and innovation. The purpose of this paper is to identify main factors affecting invention and innovation, to analyze the factors which are most important, and to give some suggestions about getting more inventions and innovations on the basis of the above analysis, especially as they may apply to conditions in the People's Republic of China.

Before moving to a discussion of factors affecting invention and innovation in science and technology, it may be helpful to summarize briefly several issues that cover most basic conceptions in this field.

2. Highlights on Invention and Innovation

2.1. Definition of Invention and Innovation

With respect to a definition of invention and innovation, we observe that different countries, scientists and engineers, and academic areas may have different understandings. Even in the same country, people at different historical periods may also have different descriptions and expressions. So it is difficult to unify the definition of invention and innovation at present.

The economist J. Schmookler in his book, Invention and Economic Growth, said:(4)

> Every invention is (a) a new combination of (b) pre-existing knowledge which (c) satisfies some wants.
> When an enterprise produces a good or service or uses a method or input that is new to it, it makes a technical change.
> The first enterprise to make a given technical change is an innovator. Its action is innovation. Another enterprise making the same technical change is presumably an imitator and its action is imitation.

Larson in his article, entitled "Management for the 80´s-Challenge to Change", said:(5)

> By definition, innovation means change—discarding the old way and adopting a new one.

D. D. Roman and J. F. Puett,Jr. in their book, International Business and Technological Innovation, said:(3,p.254)

> Inovation is an inclusive term covering a wide range of operational and environmental connotations. Innovation is possible in the context of social, economic, product, process, procedural, and managerial situations. In some instances, there is a very fine line of demarcation in the above,

> especially in making a distinction between managerial and economic innovations. There is also market tendency to think of innovation primarily as product-directed innovation.

E. B. Roberts in his chaper, entitled "Influences on Innovation: Extrapolation to Biomedical Technology", said:(6)

> The process of innovation takes into account all steps leading to the generation and initial utilization of a new or improved invention. In the biomedical area an "invention" might relate to a product, a manufacturing process, or a clinical practice. Innovation requires invention plus exploitation, which comprises such activities as the evaluation of technology; the focusing of technological development efforts toward particular objectives; the transfer of research results; and the eventual broad-based utilization, dissemination, and diffusion of research outcomes. All of these activities are potential areas of managerial or policy concern for enhancing the rate of outcomes derived from technological innovation.

G. Mensch(7) defines basic innovations as

> Innovations which produce new markets and industrial branches...or open new realms of activity in the cultural sphere, in public administration, and social services. Basic innovations create a new type of human activity.

A document published by the U.S. Department of Commerce said:(8)

> The innovation process is only one phase of a cycle. The complete cycle is invention, innovation, and diffusion. Invention is distinct from innovation and is the first stage in the cycle. Invention involves the demonstration of a new technical idea by designing, developing, and testing a working example of either a process, a product, or a device. Invention is a separate and distinct area from innovation, but it must be remembered that invention is frequently the prelude to innovation, which is primarily a conversion process leading to application. A much simpler distinction between invention and innovation revolves around the verbs"to conceive" and "to use". Invention entails a conception of an idea, whereas innovation is use, wherein the idea or invention is translated into economy.

The Patent Law of the People's Republic of China (promulgated by the Chairman of the PRC on March 12, 1984) and its Implementing Regulation (Approved by the State Council and promulgated by the Patent Office of the PRC on January 19, 1985) said:(9-10)

> Invention—Creation in the Patent Law of the PRC means Invention, Utility Model, and Design.
> Invention in the Patent Law of the PRC means any new technical solution relating to a product, a process, or improvement thereof.
> Utility Model in the Patent Law of the PRC means any new technical solution relating to the shape, the structure,

> or their combination, of a product, which is fit for practical use.
>
> Design in the Patent Law of the PRC means any new design of the shape, pattern, color, or their combination, of a product, which creates an aesthetic feeling and is fit for industrial application.
>
> Inventor or Creator in the Patent Law of the PRC refers to any person who has made creative contributions to the substantive features of the invention—creation. Any person who, during the course of accomplishing the invention—creation, is responsible only for organization work, or who offers facilities for making use of material means, or who takes part in other auxiliary functions, shall not be considered as inventor or creator.

Of course, we can cite more definitions of invention and innovation. The important thing here is neither definition itself, nor distinguishing invention from innovation. Most important are the common features of invention and innovation.

The major common characteristics of them, we emphasize here, are that they contain creative labor, including creative mental and manual labor, such as new ideas, new technical solutions, new products, new processes, and new applications, which are really different from older ones. Every thing here should connect with one word "new". In other words, achievements through creative labor must be truely new in order to regard them as invention or innovation. From this perspective invention and innovation have the same meaning and for convenience hereinafter we refer to both of them simply as "innovation".

2.2. Classification of Innovation

As earlier noted, innovation is an inclusive term covering a wide range of operational and environmental connotations. Broadly speaking, innovation can be divided into social innovation, economic innovation, product innovation, process innovation, procedural innovations, etc.(12) In the past few years there is a growing body of literature on innovation. Various aspects of innovation have been investigated by many scientists, professors, and managers. Recently, there is a tendency for classification of innovation into two types, especially in the technological areas: product innovation and process innovation. We describe briefly these innovation categories.

2.2.1. Social Innovation

Innovation which can solve public sector problems is called social innovation. Some people think social innovation and government involvement are practically inexorable. Some of the more obvious public problems in need of innovative solutions are urban renewal, environmental pollution, crime and terrorism prevention, water purity and shortage, public transportation, disease eradication and health maintenance, the elimination of poverty, highway safety, and public education. The solving of social problems usually entails interaction and cooperation between public and private sectors. At times, individual innovations in the industrial sector have created conditions which necessitate social innovation in the public domain. Conversely, there are instances when the advancement of individual innovations is also dependent upon the environment of social innovations.

2.2.2. Economic Innovation

Innovation which can create economic effects is called economic innovation. A lot of innovations, especially technological innovations, result in economic effects. There is a strong consensus that technological innovation is important, but the social and economic effects of R & D specifically, and innovation generally, are not known well enough to present quantitative indicators with confidence. Many of the studies that have been conducted differ as to method, range, and conceptualization; this adds to the difficulty of formulating a composite picture. However, some of the conclusions that might be inferred from these studies are:(3,p.255)

(1) There is a positive, high, and significant contribution of innovation to economic growth and productivity.

(2) The investment in R & D and innovation yields a return as high or often greater than the return from other investments.

(3) There are benefits to the industries which purchase new and/or improved products from innovating companies. Often, the benefits to the recipients of innovative technology equal or exceed the direct benefits to the innovating companies.

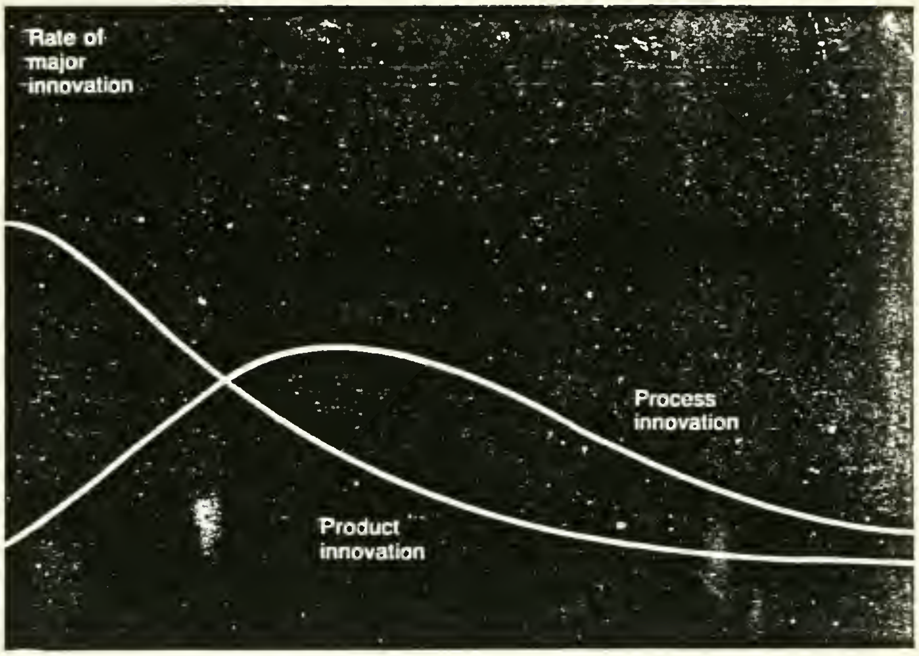
(4) There may be underinvestment in R & D and innovation relative to the future potential benefits to the firm and to society.

(5) Existing measures of economic performance, such as Gross National Product or Productivity Indices, are only partially reflective of the contribution that R & D and innovation make to the economy.

2.2.3. Product Innovation

Innovation which can lead to new products is called product innovation. Figure 1 shows a typical product innovation curve. The whole

The changing character of innovation, and its changing role in corporate advance. Seeking to understand the variables that determine successful strategies for innovation, the authors focus on three stages in the evolution of a successful enterprise: its period of flexibility, in which the enterprise seeks to capitalize on its advantages where they offer greatest advantages; its intermediate years, in which major products are used more widely; and its full maturity, when prosperity is assured by leadership in several principal products and technologies



	Fluid pattern	**Transitional pattern**	**Specific pattern**
Competitive emphasis on	Functional product performance	Product variation	Cost reduction
Innovation stimulated by	Information on users' needs and users' technical inputs	Opportunities created by expanding internal technical capability	Pressure to reduce cost and improve quality
Predominant type of innovation	Frequent major changes in products	Major process changes required by rising volume	Incremental for product and process, with cumulative improvement in productivity and quality
Product line	Diverse, often including custom designs	Includes at least one product design stable enough to have significant production volume	Mostly undifferentiated standard products
Production processes	Flexible and inefficient; major changes easily accommodated	Becoming more rigid, with changes occurring in major steps	Efficient, capital-intensive, and rigid; cost of change is high
Equipment	General-purpose, requiring highly skilled labor	Some subprocesses automated, creating "islands of automation"	Special-purpose, mostly automatic with labor tasks mainly monitoring and control
Materials	Inputs are limited to generally-available materials	Specialized materials may be demanded from some suppliers	Specialized materials will be demanded; if not available, vertical integration will be extensive
Plant	Small-scale, located near user or source of technology	General-purpose with specialized sections	Large-scale, highly specific to particular products
Organizational control is	Informal and entrepreneurial	Through liaison relationships, project and task groups	Through emphasis on structure, goals, and rules

Fig. 1. Product and Process Innovation Curves and Their Patterns
Source: W. J. Abernathy and J. M. Utterback(11)

life cycle of product and process innovation can be divided into three patterns: Fluid Pattern, Transitional Pattern, and Specific Pattern.(11) Each of them has its own behavior. From this figure, we can see that the rate of major product innovation decreases with the development of a given technological field. There is a relatively predictable pattern of the amount and type of innovation over the product life cycle. In the introductory stage there is a relatively large amount of product innovation. At the start of the growth stage of the technology the total amount of innovation starts to decrease and the type of innovation shifts to a combination of major process innovation and more incremental product innovation. This pattern continues until the product and its associated production processes become so intertwined that primarily incremental process innovation occurs.

2.2.4. Process Innovation

Innovations which modify, improve, or substitute for the original product manufacturing process are called process innovations. In order to compare with the product innovation situation, Figure 1 also shows the typical process innovation curve. In the spectrum of innovation, process innovation affords considerable latitude. Process innovation can reduce production costs, increase profits, improve the organization´s competitive position, and enable the firm to penetrate markets that were previously not economically feasible. In short, the successful introduction of the products may be directly related to product producibility. Producibility, especially with new products, may be contingent on process innovation. Process innovation may occur in large or small organizations. But, normally, process innovation is a large-enterprise activity where economies of scale provide innovational incentives.

2.2.5. Procedural Innovations

Innovations which change the original, routine procedures to meet new situations are called procedural innovations. Compared with other "hard innovation", it is "soft innovation". With development of science and technology, the basic tasks of some firms, scientific research institutes, or other units may change. In this case, operational forms and operational climates may also change, albeit at times unperceptibly. Often, original routines or procedures are not reviewed or recast innovatively to reflect shifts in operations and may become bogged down. Procedural innovation, in mechanical processes or thinking processes, can be instrumental in more effectively utilizing the organization´s resources. This, unfortunately, is often a neglected area, but it offers fertile innovational possibilities.

In addition to these classifications, different academic areas and different countries at times may have different methods of classification. For example, the Patent Law of the People´s Republic of China divided invention-creation into three types: "Invention", "Utility Model", and "Design"(9). Roberts said(6):

> Innovations can be classified into the following overlapping set of typologies:
>
> Products vs. processes vs. practices
>
> Radical developments vs. incremental changes
>
> New items vs. modifications of existing items
>
> Industrial goods vs. consumer goods
>
> Services

Graham and Senge(12) distinguish between basic innovation and improvement innovation. The definition of basic innovation we have cited earlier(in 2.1.), improvement innovation can be thought of as incremental improvements on an existing technology that do not alter its fundamental nature.

2.3. Process of Innovation

The development of an innovation from the idea-generation phase through to introduction and commercialization is inherently an interfunctional process. Figure 2 shows the typical model of the whole process of innovation.(13) From this figure we can see two broad arrows representing the major sources of inputs for the process, which is shown taking place schematically between them. Beneath everything is a temporal scale which shows the principal stages in the process. The events in these stages will not, of course, always occur in the linear sequence implied by the sketch, nor will each segment be equal in duration. The process of innovation may be viewed as occurring in three stages or phases(13-14): generation of an idea (recognition-idea formulation); problem solving or

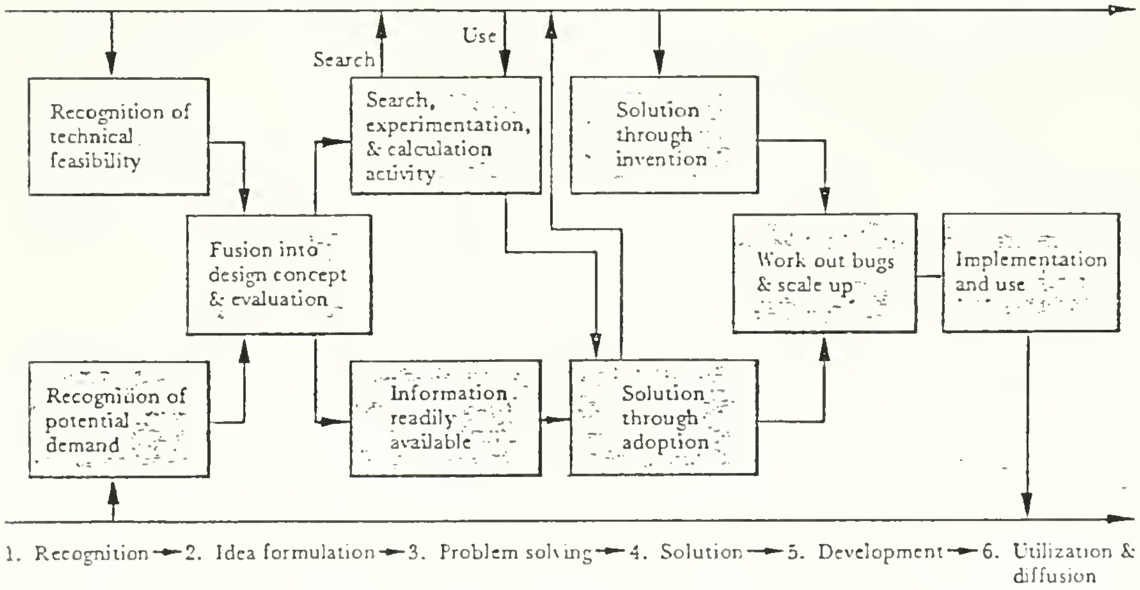


Fig. 2. Model of the Process of Innovation
Source: D. G. Marquis(13,P.44)

development of the idea (problem solving-solution); and implementation and diffusion of the development in useful form (development-utilization & diffusion).

Successful innovation begins with a new idea which involves the recognition of both technical feasibility and demand. Then comes the idea formulation which consists of the fusion of a recognized demand and a recognized technical feasibility into a design concept. This is truly a creative act in which the association of both elements is essential. The design concept is only the identification and formulation of a problem worth committing resources to work on. Then comes the problem solving stage. The problem solving or development of the idea involves setting specific goals and designing alternative solutions to meet them. If the problem solving activity is successful, a solution--often in the form of an invention--is formed. Implementation and diffusion of the development consists of engineering, tooling, and plant and market start-up required to bring an original solution or invention to its first use or market introduction. Innovation is never really achieved until the item is introduced into the actual market or production process, and sales or cost reductions are achieved.

2.4. Theories of Innovation

2.4.1. On Evolution

W. J. Abernathy and J. M. Utterback(11) have examined how the kinds of innovations attempted by productive units apparently change as these units evolve. Their goal was a model relating patterns of innovation within a unit to that unit´s competitive strategy, production capabilities, and organizational characteristics. A new model suggests how the character of its innovation changes as a successful enterprise matures; and how other companies may change themselves to foster innovation as they grow and prosper. Summarizing their work and presenting the basic characteristics of the model on patterns of industrial innovation, Abernathy and Utterback concluded that a productive unit's capacity for and methods of innovation depend critically on its stage of evolution from a small technology-based enterprise to a major high-volume producer. Many characteristics of innovation and the innovative process correlate with such an historical analysis; and on this basis they explain some major questions which relate to the theory of innovation. They argue that two units--the small, entrepreneurial organization and the large unit producing standard products in high volume—are at opposite ends of a spectrum of innovations. In a sense, they form boundary conditions in the evolution of a unit and in the character of its innovation of product and process technologies. Also, the authors present examples of a series of successful innovations and established high-volume products, such as incandescent light bulbs, paper, steel, standard chemicals, and the internal-combustion engine.

2.4.2. On a Long-Wave Hypothesis

Long-waves in economic growth and innovation have been discussed by many economists.(7,15) The main point of this hypothesis is that the flow of basic innovations into developed economies appears to occur in waves. According to this unproven argument, brief periods of high receptivity to basic innovations occur every 40-60 years: in between, economic conditions favor less radical improvement innovations. Lagging productivity and innovation is a natural consequence of a long-wave in economic behavior. This long wave is also characterized by buildup, overexpansion, and relative decline of capital-producing sectors. The long wave creates a shifting historical context for the implementation of new innovations. Midway into a capital expansion, opportunities for applying new inventions that require new types of capital may become poor. During a long wave downturn, basic innovation opportunities gradually improve, as old capital embodying the technologies of the preceding buildup depreciates. Near the trough of the wave, there are great opportunities for creating new capital-embodying radical new technologies.

G. Mensch(7) has presented a variety of data on long-term trends in innovation which are consistent with the long-wave hypothesis. Figure 3 shows the frequency of basic innovations in western countries in 22 10-year periods from 1740 to 1960. Figure 3 suggests distinct periods in history that uniquely favor basic innovations: in the 1760s, the 1820s and 1830s, the 1880s, and the 1930s. These periods of intense innovation correspond to troughs in the long wave.

Although economic long waves can be explained without new innovations as an explicit causal factor, the long-wave theory has important implications for innovation. This theory is consistent with the general

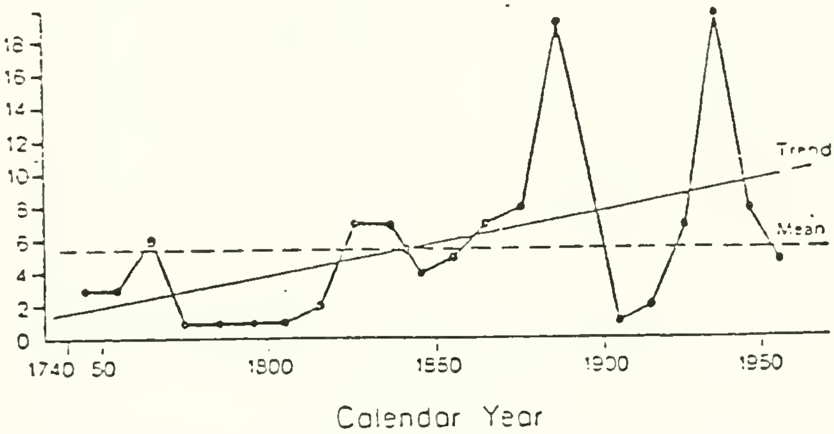


Fig. 3. Frequency of Basic Innovation(1740-1960)
Source: G. Mensch(7,P.130) or (12,P.300)

trend of the development of history: the development of anything in the world goes up in spirals and advances in waves.

3. Internal Factors

As noted above, innovation is a complex interfunctional process. During the whole process of an innovation, many factors affect it, including features of academic areas, personnel structure, managerial strategy, internal policy, organizational form, scale of unit, environmental conditions, market incentives, cooperation and communication, and the role of government, etc. When we look at a complex thing, we must learn and use dialectical, reliable, and scientific methods of analysis. By analysis, we mean identifying and assessing main factors which may affect innovation. But this does not mean that every factor has the same importance. One or some of them must be the principal factors playing the leading and decisive role, while the rest occupy a secondary and subordinate position. So our tasks are not only to analyse all of these factors, but also to find its principal and decisive factors. Finally, we must also solve the problem of the methods for carrying these factors into use as part of strategy or tactics. For example, if our task is to cross a river, we cannot cross it without a bridge or a boat. Unless the bridge or boat problem is solved, it is idle to speak of crossing the river. Unless the problem of method is solved, talk about the task is useless.

Through generalization, we can divide all of these factors affecting innovation into two kinds: internal factors and external factors. By internal factors, we mean these factors: 1) They exist in every thing, every group, every program, every department, every institute or university, usually within a certain unit. The scope depends on what you want to research or analyze; 2) Sometimes, they can be controlled or decided by ourselves. In other words, we may have the power to make decisions on these factors. In our case, we would like to focus on the scientific research institute as background. The basic methods of analysis are also suitable for other corporate, company, or university organizations.

Similarly, we can identify external factors which exist outside of a certain unit or beyond our control.

In accord to these rules mentioned above, internal factors include the features of academic areas, personnel structure, managerial strategy, internal policy, organizational form, scale of unit (size); while external factors include environmental conditions, market incentives, cooperation and communication, and the role of government. Generally speaking, the fundamental cause of the development of a thing is not external but internal; while its interrelations and interactions with other things are secondary causes. That is, external factors are the conditions of change and internal factors are the basis of change. External factors become operative through internal factors. For example, in a suitable temperature an egg changes into a chicken, but no temperature can change a stone into a chicken, because each has a different basis. Similarly, social development is due chiefly not to external but to internal causes. Countries with almost the same geographical and climatic conditions display great diversity and unevenness in their development.

But this situation is not static; internal and external factors are a relative notion. In a given process or at a given stage in the development of a thing, sometimes external factors may become the leading and decisive role player. So, the most essential thing is a concrete analysis of concrete conditions. We do want to go deeply into complex matters, to analyze and study them over and over again. Surely, we can draw correct conclusions in the end.

3.1. Features of Academic Areas

3.1.1. Different Areas Have Different Objects of Study

Every thing in the universe is in motion and has its own particular forms of motion. Science and technology are the same. Man´s knowledge of matter is knowledge of its forms of motion. In considering each form of motion of matter, we must observe the points which it has in common with other forms of motion. But what is especially important and necessary, constituting as it does the foundation of our knowledge of a thing, is to observe what is particular to this form of motion of matter, namely, to observe the qualitative difference between this form of matter and other forms. Only when we have done so can we distinguish between things. The areas of science are differentiated precisely on the basis of the particular forms of motion of matter inherent in their respective objects of study. Thus the forms of motion particular to a certain field of phenomena constitute the objects of study for a specific branch of science. For example, positive and negative numbers in mathematics; action and reaction in mechanics; positive and negative electrical charges in physics; dissociation and combination in chemistry; offence and defence in military science; idealism and materialism, the metaphysical outlook and the dialectical outlook, in philosophy; forces of production and relations of production in social science; and so on. All these forms are interdependent, but in its essence each is different from the others. Each branch of science can also be divided into some sub-branches. For example, chemistry can be further divided into general chemistry, organic chemistry, inorganic chemistry, electrochemistry, quantum chemistry, biological chemistry, physical chemistry, applied chemistry, theoretical chemistry, colloid chemistry, etc. All these are the objects of study of different branches of science precisely because each branch has its own particular essence.

3.1.2. Different Objects of Study Have Different Specific Problems

Different branches of sciences, different academic areas, of course, have their own specific problems to be resolved due to the different objects of study. On the other hand, qualitatively different problems can only be resolved by qualitatively different methods. Therefore, the degree of difficulty to be resolved for each branch or each academic area is quite different. Thus, the problems arising in the different academic areas or different branches of science will be resolved at different periods of time. Some problems will be resolved easily and early. The more difficult the problems are to be resolved, the later they will be overcome. In other words, at the same period of time , the number of achievements in different academic areas are different completely. This point of view has been proven by many statistical analyses. Table 1 shows the number of U.S. patents granted to selected foreign countries by product field for the period of 1963-1981. It should be noted that people working in different areas face different kinds of problems, thus affecting innovation. Those who work in easier areas may obtain more achievements than other people who have equivalent ability but work in more difficult areas.

3.1.3. Unevenness of Development in Science and Technology

The process of science and technology develops step by step from simple to complex, from the shallower to the deeper, from the one-side to

Table 1. Number of U.S. patents granted to selected foreign countries[1] by product field for the period 1963–81

Country of Inventor	All fields	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Total	1,234,643	14,105	12,753	201,786	30,945	17,098	64,353	29,825	16,307	157,200	385,768	133,272	143,156	78,246	27,201	149,425
United States	865,124	9,725	8,235	128,369	17,407	14,596	46,698	21,594	10,204	118,688	264,670	96,556	101,914	53,738	16,931	103,333
Foreign	369,519	4,380	4,518	73,417	13,538	2,502	17,655	8,231	6,103	38,512	121,098	36,716	41,242	24,508	10,270	46,092
West Germany	91,359	589*	1,368*	21,060*	3,135*	456*	4,092*	1,742*	1,245*	8,973*	31,624*	8,462*	7,850*	6,762*	2,748*	11,145*
Japan	77,450	1,534*	877*	15,139*	2,277*	339*	3,767*	1,747*	1,399*	6,032*	20,857*	8,416*	13,013*	4,698*	2,637*	13,353*
United Kingdom	51,138	463*	707*	9,238*	1,820*	531*	2,750*	1,416*	772*	5,990*	17,233*	5,317*	5,976*	4,080*	1,845*	5,478*
France	35,244	305*	337*	6,722*	1,607*	252*	1,720*	864*	588*	3,919*	11,100*	3,758*	4,455*	2,913*	1,229*	3,645*
Switzerland	21,622	245	483*	7,011*	1,496*	57	747	265	254	1,924	6,487	1,906*	1,258	871	179	2,527*
Canada	20,241	248*	130	2,307	444	353*	1,067*	456*	419*	3,030*	7,082*	1,839	1,773	1,382*	373*	1,763
Sweden	13,368	128	103	924	307	47	761	407	320	2,194	5,713	1,348	1,007	1,099	298	1,491
Italy	11,958	116	135	3,122	682	48	578	191	150	1,097	4,283	1,068	847	648	243	932
Netherlands	11,103	232	82	2,129	350	182	498	236	98	1,057	3,195	1,473	2,701*	363	131	1,007
U S S R.	5,111	54	25	759	94	62	93	113	188	359	2,228	813	454	153	63	616
Belgium	4,459	37	55	1,074	188	31	245	175	90	410	1,186	264	360	157	28	945
Austria	4,080	35	22	433	91	19	201	88	153	504	1,795	250	273	205	80	449
Australia	3,585	48	40	454	82	17	219	96	80	581	1,365	246	198	212	76	483
Denmark	2,520	81	29	329	115	7	160	80	11	391	947	295	161	62	30	373
Mexico	1,075	28	5	428	339	3	45	20	31	113	259	44	21	50	23	80
Other foreign[2]	15,206	237	120	2,288	511	98	712	335	305	1,938	5,744	1,217	895	853	287	1,805

*Indicates ranking among the top five foreign countries in this particular product field

[1] Countries were selected on the basis of being in the top 10 of at least one of the Standard Industrial Classifications.

[2] Other foreign includes patents granted to foreign countries not shown separately

I	Food and kindred products
II	Textile mill products
III	Chemicals, except drugs and medicines
IV	Drugs and medicines
V	Petroleum and gas extraction and petroleum refining
VI	Rubber and miscellaneous plastics products
VII	Stone, clay, glass, and concrete products
VIII	Primary metals
IX	Fabricated metals
X	Nonelectrical machinery
XI	Electrical equipment except communication equipment
XII	Communication equipment and electronic components
XIII	Motor vehicles and other transportation equipment except aircraft
XIV	Aircraft and parts
XV	Professional and scientific instruments

SOURCE: Compiled from information in Office of Technology Assessment and Forecast, U S Patent and Trademark Office, *Indicators of the Patent Output of U S Industry IV (1963-81)*, 1982.

Science Indicators—1982

the many-sides, from the macrocosm to microcosm, from a lower to a higher level, from the perceptual stage to the rational stage. From long long ago, mankind used five sense organs (the organs of sight, hearing, smell, taste, and touch) only to observe simple things and understand them incompletely. At that time, the knowledge men obtained was perceptual knowledge. After some development, mankind learned gradually how to create and operate many different types of machines which can be regarded as extensions of mankind´s sense organs. Start from perceptual knowledge and actively develop it into rational knowledge; then start from rational knowledge and actively guide revolutionary practice to change both the subjective and the objective world. Practice, knowledge, again practice, and again knowledge. This form repeats itself in endless cycles, and with each cycle the content of practice and knowledge rises to a higher level. Therefore, science and technology are developing rapidly.

But, the speed of development of science and technology for every country is quite different due to a lot of internal and external factors. Some countries, such as the United States and Japan, have rapidly developed in science and technology during the past few decades and have become the first-rate industrialized countries in the world. This unevenness of development in science and technology is absolute and basic, while evenness in any time is only relative and temporary. This unevenness of development will heavily affect innovation. The features of academic areas relate closely to the whole level of every country in science and technology. It is very difficult for us to imagine that if we worked in those countries or ages which have no transistor and integrated circuits, we could create high quality radios and color TV sets. Therefore, a technological problem encountered in a developing country may be resolved with great difficulty. But if the same technological problem were put in a

Table 2. Percent of Patent Applications of Subclasses—
Ceramic Coating Materials in the World

Year	U.S.	Japan	West Germany	U.K.	France	All Other	Total
1963-1970	84	4	4	3	-	5	100
1970	72	16	12	-	-	-	100
1971	69	11	-	8	-	12	100
1972	60	8	13	13	3	3	100
1973	71	4	2	6	6	11	100
1974	68	10	5	3	3	11	100
1975	61	14	7	2	-	16	100
1976	58	9	17	4	1	11	100
1977	65	13	8	3	-	11	100
1978	49	17	14	5	3	12	100
1979	57	23	10	-	-	10	100
1980	52	30	10	4	1	3	100
1981	61	24	6	-	3	6	100
1982		Data Incomplete					
1983 (6 mo.)		Data Incomplete					

Source: U.S. Department of Commerce, Patent Technology Assessment Forecast, Custom Report by Patent and Trademark Office, September 13, 1983.

Table 3. Percent of All Ceramic Patents in the World

Year	U.S.	Japan	West Germany	U.K.	France	All Others	Total
1970	77.7	5.9	4.9	3.0	3.8	4.7	100
1971	76.2	5.5	6.2	3.1	3.8	5.2	100
1972	67.7	11.1	5.5	6.2	2.1	7.4	100
1973	68.0	10.1	5.6	4.2	2.8	9.4	100
1974	70.2	7.3	5.0	6.8	1.8	8.9	100
1975	60.5	12.1	10.1	9.1	1.7	6.5	100
1976	61.7	10.6	7.3	10.3	1.8	8.3	100
1977	59.1	14.5	7.2	7.2	2.4	9.6	100
1978	58.4	21.2	6.3	4.8	3.3	6.0	100
1979	55.7	18.9	5.8	4.7	4.7	10.2	100
1980	56.7	20.4	7.3	4.6	4.2	6.8	100
1981	55.5	23.8	8.3	3.8	3.0	5.6	100
1982	49.8	24.3	3.9	6.7	7.4	7.4	100
1983--(6mo.)	57.1	28.6	4.7	1.0	1.9	6.7	100

Source: U.S. Department of Commerce, Patent Technology Assessment Forecast, Custom Report by Patent and Trademark Office, September 13, 1983.

developed country, we may resolve it quite easily. This is a common experience proved by many scientists. In other words, developed countries have created better conditions for innovation (including knowledge resources and financial support) than developing countries. This is an important reason why developed countries have more innovations, patents, and achievements than developing countries. Table 2 shows the percent of patent applications of ceramic coating materials by countries of the world. Table 3 shows the percent of all ceramic patents in the world during the past few decades. From Tables 2 and 3 we can clearly see that the percent of patents in the developed countries, especially in U.S. and Japan, is much greater than that of developing countries.

3.2. Personnel Structure

Of all factors affecting innovation, we believe that personnel structure is the most important factor. There are many reasons for that. The main reason is that everything in the world is created by people. Of all things in the world, people are the most precious. Under the guidance of correct thinking, as long as there are people, every kind of possible miracle can be performed.

As stated above, successful technological innovation may be viewed as occurring in three stages: generation of an idea, problem solving or development of the idea, and implementation and diffusion of the development in useful form (commercialized). Corresponding to each stage are some qualitatively different tasks to be fulfilled. In order to do so well, we should also have different people in quantity and quality, who can deal with different kind of tasks in each stage. Personnel structure should be studied on several levels.

3.2.1. Different Function People Work Together

A variety of studies suggest that five different key staff roles must be fulfilled if innovation ideas are to be generated, developed, enhanced, commercialized, and moved forward in the organization.(6,16-18)

(1) Creative scientists or engineers—idea generators or idea havers.

Idea generators or idea havers are central people and have critical roles in achieving successful innovation. All successful innovations must begin with a new idea which often is based on well-known technical information. Otherwise an innovator would be like water without a source, a tree without roots. Successful innovation and the process of science and technology badly need a large contingent of creative scientists or engineers who are both knowledgeable in modern science and technology and imbued with a creative, innovative spirit and who are capable of bringing about a new situation in whatever they do. Our contingent of creative scientists and engineers in China falls far short of the above requirements.

(2) Entrepreneurs

Entrepreneurs, called"idea-exploiters" or "product champions" in some empirical studies, do something with the ideas they or others have generated and push the technical idea forward in the organization toward the point of commercialization.

(3) Project managers

Project managers, sometimes regarded as "business innovators", handle the supportive functions of planning, scheduling, business, and finance relating to the development activities of technical colleagues. In other words, the project manager organizes almost the whole of R & D activities, focuses upon the specifics of the new development, and indicates which aspects will go forward, which can be economically supported, and which must be deferred; he or she coodinates the needed efforts.

(4) Sponsors

The sponsor or coach is one kind of more senior person who is neither carrying out the research itself nor is directly championing the change, but who provides coaching, back-up, and large skirts behind which other key people can hide. His role is that of protector and advocate, and sometimes bootlegger of the resources necessary to move technological advances forward in an organization.

(5) Gatekeepers

Gatekeepers or special communicators also play an important role by providing the links whereby essential information messages are brought from outside sources to the inside world of developmental activities. They are human bridges joining technical (the technical gatekeeper), market (the market gatekeeper), and manufacturing sources of information to the potential technical users of the information.

In addition to these five roles, some people also regard technical problem-solvers and quality controllers as additional key staff.

3.2.2. Different Age People Work Together

The development of science and technology is a continuous process. The communicability of science is one of its important features. In order to guarantee the continuous development of science and technology, and to obtain more innovations, corresponding to each type of the five key staff people mentioned above, we should train and bring up successors who are different ages. The best way is that junior people (scientists, engineers, entrepreneurs, managers, gatekeepers, etc.) work together with senior people. Young people learn from senior people first and then catch up with or surpass them later. It is an important thing that as part of their

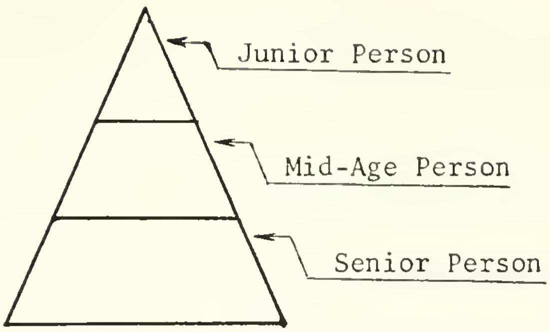
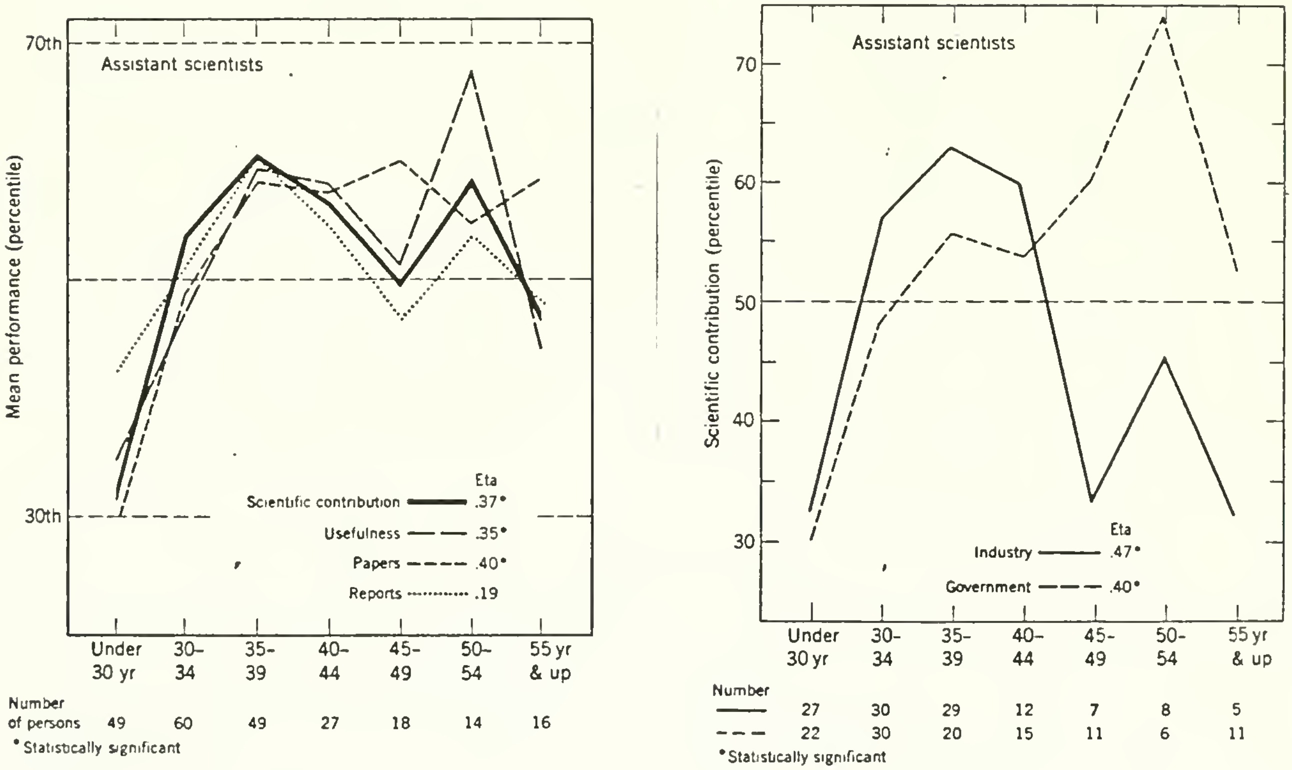


Fig. 4. Proportion of the Different Age People in a Unit (Qualitatively)



(a)

(b)

Fig. 5. The Relationships between Age of Assistant Scientists and their Mean Performance(a) and Scientific Contribution(b) Source: D. C. Pelz and F. M. Andrews(19,P.179 and P.187)

responsibilities senior people help mid-age and young people to improve their ability. The number of appropriate people of each different age depends on the task of the firm and the features of their academic areas. Usually, due to advancement of new knowledge, more young people are required than mid-age people and the latter more than senior people. We may qualitatively show them as a triangle (Figue 4) if the area of the triangle stands for the total numbers of the unit.

Many statistics have pointed to the fact that a majority of innovations were created by young or mid-age scientists and engineers.(19) The peak age of productivity for many scientists and engineers is around 35 years old. During that time, many scientists and engineers make their highest contribution to innovation and get the most achievements. Figure 5 quantitatively shows the statistical results for many scientists.

In his article, "The Problem of Aging Organizations", Prof. E. B. Roberts(20) indicated that new Ph.D. scientists make their major contributions shortly after joining an organization. Thereafter, their technical effectiveness declines. On the other hand, a young engineer´s productivity is greatest five to ten years after joining the R & D organization; after that time his creative contributions are fewer. On this basis, the technical effectiveness of the R & D group depends on a continual inflow of new people.

3.2.3. Different Title People Work Together

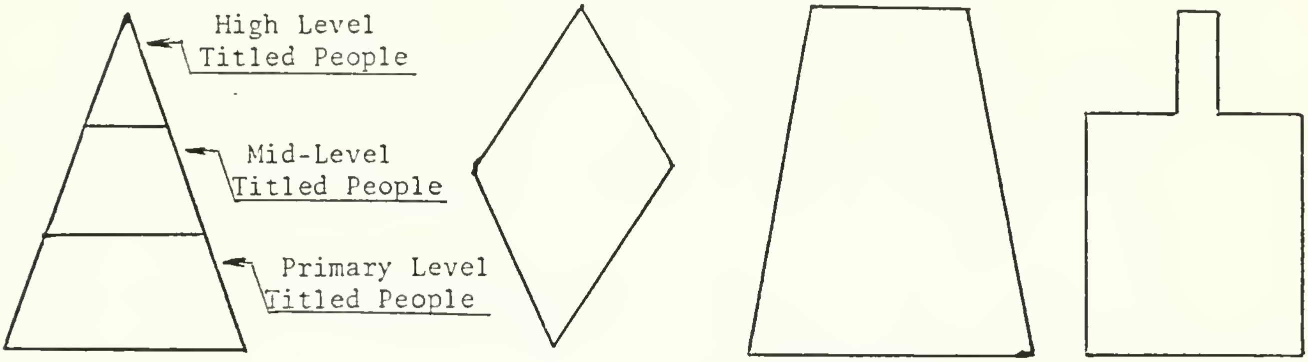
Generally speaking, title can indicate people´s ability and knowledge level. Title varies with countries and units. Full professor, associate professor, assistant professor are named in a university or institute; Chief-engineer, senior engineer, engineer, technician are named in a factory technical unit; general manager, vice general manager, manager are named in a company, etc. Usually, people who have higher level titles guide other people who have lower level titles. In the light of historical experience and the practice over years, the basic characteristics of this problem can be further summed up as follows:

(1) Every R & D organization should have its own high level, middle level, and primary level people.

(2) Those units which have no high level titled people may invite a few high level titled people from outside as guest scientists.

(3) Too many high level or mid-level people working alone in a unit or group is not good. In this case, there are likely to be a lot of conflicts arising among them. It is difficult to deal with that kind of conflicts, especially without large numbers of lower level people to carry forward detailed technical projects.

(4) We can show the structure of personnel by using geometric figures. A stable, reasonable structure of personnel shows as the isosceles triangle. Figure 6 describes some structures of personnel. All of the other structures (the rhombus, the trapezoid, jar shape, etc.) are not stable or reasonable.



(a) A Stable and Reasonable Structure

(b) Unstable and Unreasonable Structures

Fig. 6. Some Structures of Personnel

In China today our scientists and engineers who are first-rate by world standards are too small in number as a whole. Mid-level title people in some units, especially in the system of the Chinese Academy of Science, are too large. The structure of personnel in those units shows as the rhombus (figure 6(b)). In these units some conflicts arise very often between the same level people. The author has dealt with that kind of matter many times. So unstable structures of personnel will negatively affect innovation.

3.2.4. Different Field People Work Together

The solution of a problem in modern science and technology is extremely complex. So is innovation. In modern society the solution of a problem is usually the result of integration of many opinions, suggestions, and proposals. When you intend to resolve a complex technical problem which relates to successful innovation, you very often need people from different fields who can propose alternative solutions from different angles which relate some special academic areas. Every person may know his own specialty very well. The solutions or suggestions proposed are often high in value. In this sense, some people have pointed out "1 + 1 does not equal 2" and "1 + 1 > 2", the system plays a role as amplifier. That means if we compare two groups, one which is made up of 5 persons from the same field, and another also made up of 5 persons but from different fields (such as a physicist plus a chemist plus a technician plus..., who can fill in the gaps to complete a chain of the program), under the same conditions (such as cooperation, qualification, and other external environments) the creativity of the latter usually is greater than the former. There is a synergistic effect for the varied group.

3.3. Managerial Strategy

Management is a major variable in the innovation process. Management should be an instigating or moving force in innovational possibilities. Organizations usually reflect management´s strategy and operational policies. We should master modern methods of scientific management.

The task of managerial strategy in innovation is to study those methods of thinking for directing an innovation that govern an innovation as a whole. Therefore, it relates to a series of key questions concerning innovation. We may say that managerial strategy plays a dominant role in the success or failure of a business unit. The management of a stream of innovations over time is exceptionally complex. Most new products or new businesses fail, many successful small firms do not make the transition to more mature larger organizations, and many large firms become ever more bureaucratized thereby stifling their ability to innovate. Some companies may be unwilling to depend on other companies for licenses, may want to keep at the forefront of technology, and yet may also be reluctant to incur the developmental costs in the light of risk and product life uncertainties. So, today´s manager is confronted with a greater number and variety of problems than before. The manager´s job is not only to solve well-defined problems, he must also identify the problems to be solved. He must somehow assess the cost of analysis and its potential return. He must allocate resources to questions before he knows their answers. In short, management´s primary job is to make organizations operate effectively.

3.3.1. Managerial Strategy Varies with the Stage of Innovation

As we have already indicated, there are some different patterns and types of innovation over the product life cycle. During the different stages of the product life cycle (introductory stage, growth stage, mature stage, and decline stage), different strategies and organizational forms are appropriate. The introductory stage begins with the development and introduction of a product innovation that starts a new product class life cycle, and runs until many of the products start to be manufactured in higher volume. The basis of competition here is product performance. The business units are typically small entrepreneurial ventures. Their strategy is to take an incompletely understood technology and an ill-defined market and to produce a product with superior functional performance, even if the product is expensive. During the growth stage, major process innovations begin to increase the interdependence between the product and the manufacturing process. The decision to standardize the product (high quality, low costs), to reduce the costs of the product, and to ensure adequate distribution are the main strategies in this stage. The mature stage is a time of little or no sales growth. In this stage, the common denominator of success is one of the following strategies: 1) achieve the lowest delivered cost position relative to the competition, 2) achieve the highest product/service quality differentiated position (sometimes achieved through product redesign), or 3) follow both strategies simultaneously. Tables 4 and 5 show the variation of strategies over the product life cycle and typical functional requirements of alternative technological strategies.(21-22)

3.3.2. Setting the Feasible Goal

Every country, every firm, and every unit has its own situation and environment. Also, they have their specific goals and tasks which should suit their own situations and environments. Those who are working toward specific goals should know: 1) where we are now, 2) where we are going, 3) what methods we should take for achieving the goals. People should firmly

Table 4. Variation of Strategic and Organizational Factors over the Product Life Cycle

	PRODUCT LIFE CYCLE STAGE								
	INTRODUCTION				GROWTH		MATURE		
TYPE OF INNOVATION	MAJOR PRODUCT INNOVATION	→			INCREMENTAL PRODUCT/MAJOR PROCESS INNOVATION	→	INCREMENTAL PRODUCT/PROCESS INNOVATION		
LOCATION OF INNOVATION	ENTREPRENEUR	→	MARKETING/ R & D	→	MARKETING/ PRODUCTION	→	PRODUCTION		
BASES OF COMPETITION	PRODUCT PERFORMANCE	→			PRODUCT DIFFERENTIATION PRICE	→	PRICE IMAGE MINOR DIFFERENCES		
PRODUCTION PROCESS	JOB SHOP	→	BATCH	→	ISLANDS OF AUTOMATION	→	ASSEMBLY LINE	→	CONTINUOUS FLOW
DOMINANT FUNCTION	ENTREPRENEUR	→	MARKETING/ R & D	→	MARKETING/ PRODUCTION	→	PRODUCTION/ SALES (PROMOTION)		
MANAGEMENT ROLE	ENTREPRENEUR	→	SOPHISTICATED MARKET MANAGER	→	ADMINISTRATOR/INTEGRATOR	→	STEWARD		
MODES OF INTEGRATION	INFORMAL COMMUNICATION	→	INFORMAL COMMUNICATION TASK FORCES TEAMS	→	INFORMAL COMMUNICATION TEAMS PROJECT MANAGER	→	FORMAL COMMUNICATION SENIOR MANAGEMENT COMMITTEES		
ORGANIZATIONAL STRUCTURE	FREE FORM	→	FUNCTIONAL ORGANIC	→	PROJECT/ MATRIX	→	FUNCTIONAL/ BUREAUCRATIC		

Source: W. L. Moore and M. L. Tushman (21,p.143)

Table 5. Corporate Strategy and Technological Policy

	Typical Functional Requirements of Alternative Technological Strategies					
	R & D	Manufacturing	Marketing	Finance	Organization	Timing
First-to-Market	Requires state of the art R & D	Emphasis on pilot and medium-scale manufacturing	Emphasis on stimulating primary demand	Requires access to risk capital	Emphasis on flexibility over efficiency; encourage risk taking	Early-entry inaugurates the product life cycle
Second-to-Market	Requires flexible, responsive and advanced R & D capability	Requires agility in setting up manufacturing medium scale	Must differentiate the product; stimulate secondary demand	Requires rapid commitment of medium to large quantities of capital	Combine elements of flexibility and efficiency	Entry early in growth stage
Late-to-Market or Cost Minimization	Requires skill in process development and cost effective product	Requires efficiency and automation for large-scale production	Must minimize selling and distribution costs	Requires access to capital in large amounts	Emphasis on efficiency and hierarchical control; procedures rigidly enforced	Entry during late growth or early maturity
Market-Segmentation	Requires ability in applications, custom engineering, and advanced product design	Requires flexibility on short- to medium runs	Must identify and reach favorable segments	Requires access to capital in medium or large amounts	Flexibility and control required in serving different customers' requirements	Entry during growth stage

Source: M. A. Maidique and Peter Patch (22,P.279) keep these three questions in their mind. Only then can we achieve the anticipated results. A good example is the success of Texas Instruments (TI) in producing its new product named "Speak and Spell", a battery-operated hand-held device designed to help children learn to spell. The heart of the device is a tiny semiconductor chip capable of speech synthesis. Stimulated by early indications of strong market demand, TI, which pioneered in commercialization of silicon transistors and later in integrated circuits (these two are important technological bases for the new successful product), tried to create this new product. After P. Breedlove (an electrical engineer) provided the core idea that paved the way to development of this product, successive stages involved proof of feasibility, funding the project, resolving key technological problems, design-to-cost, assessing the market, manufacturing the product, and getting ready for the product launch stage, etc. The goal of each stage is very clear and feasible. So "Speak and Spell" thereafter became a successful new product.

The emphasis here is that the goal we would like to achieve must be feasible. If a man(or any unit) wants to succeed in his work, that is, to achieve the anticipated results, he must bring his ideas into correspondence with the laws of the objective external world. If they do not correspond, he will fail in his practice. After he fails, he draws his lessons, corrects his ideas to make them correspond to the laws of the external world, and can thus turn failure into success; this is what is meant by "failure is the mother of success" and "a fall into the pit, a gain in your wit". For example, after World War II, under the leadship of Charles De Gaulle, France launched an ambitious science policy program aimed at achieving a high level of technological excellence and international technological independence. In the Post-World War II period, France, perhaps along with the United States and Soviet Union, had the broadest technological aspirations of any of the developed nations of the world. In fact, the De Gaulle-inspired program met with significant, but limited, success. There were significant technological achievements, especially in the development of military weapons systems and atomic energy. However, it became apparent that as a nation France did not have the resources to compete worldwide in all technological areas. Developed nations have generally come to the realization that total technological excellence is not a viable policy and have as a consequence generally retreated to a defensible position of concentration to develop spheres of technological eminence where they have international competitive advantages; such as defence industry, atomic energy, and electronics to name a few. France appears, for example, to have moved in this direction.

3.3.3. Paint a Picture with Two Brushes at the Same Time—"Work Along Both Lines" Strategy

In order to obtain more innovations and develop new products, we can take two ways. One is to participate in the new technology and develop new products according to analysis of the market and the nature of the unit. "If you can´t beat them, join them" is a good defensive strategy. Another is to refine or modify earlier products. We named these as the "work along both lines strategy". The main reasons for this strategy are:

(1) A new product may be a variation on an old one, or reorientation. A variation is a product with a set of dimensions basically similar to those of earlier products of the organization, though with refinements and modifications. The yearly model changes of American cars would be a typical example. Various alumina ware in new inorganic non-metallic materials would be another typical example. A reorientation usually

implies more fundamental changes, in which some product dimensions may be eliminated and entirely new ones added.

(2) Cooper and Schendel analyzed the sales data of seven threatened industries and technologies selected for study (steam locomotives vs. diesel-electric, vacuum tubes vs. the transistor, fountain pens vs. ball-point pens, boilers for fossil fuel power plants vs. nuclear power plants, safety razors vs. electric razors, aircraft propellers vs. jet engines, leather vs. polyvinyl chloride and poromeric plastics), coupled with extensive examination of other information and then made a number of conclusions concerning the substitution pattern of new for old technologies.(23) They pointed out that in most situations, after the introduction of the new technology the sales of the old technology did not necessarily decline immediately; they continued to expand, despite growth in sales of the new technology. When sales of the old technology did decline, the time period from first commercial introduction to the time when dollar sales of the new technology exceeded dollar sales of the old ranged from about five to fourteen years. The new technology often created new markets which were not availuble to the old technology. Sometimes, the new technology was expensive and relatively crude at first. Often its initial shortcoming led observers to believe it would find only limited applications. Thus, it may be advisable to take the "work along both lines strategy".

3.3.4. Venture Strategy

Venture strategy is one of the important managerial strategies. An increasing number of writings have focused on this topic.(24-28) Edward B. Roberts has given his spectrum of venture strategies (24), ranging from those requiring only low corporate involvement, such as venture capital, to those requiring high corporate involvement, such as internal ventures. A spectrum of entry strategies for success was presented in his article "Entering New Businesses: Selecting Strategies for Success".(29) Entering a new business (new products or new applications) may be achieved by means of a variety of mechanisms such as internal development, acquisition, joint ventures and minority investments of venture capital. Each of these mechanisms makes different demands upon the corporation. No one strategy is ideal for all new business development situations.

Here we would like to say a few words about the China situation. China is a large country, a sleeping lion, but now economically backward and poor. China closed its door to western countries for a long time, a strategic mistake. Taught by mistakes and setbacks, Chinese people have become wiser and handle their affairs better. China now takes an open policy to the world. The Chinese government has decided that this policy is a longstanding strategy and an important part of its economic reforms. Venture strategy is one of its important decision-making approaches. Some mechanisms are as follows:

(1) Joint Ventures

For example, China and Japan will start a joint venture soon to develop a magnesite mine in northeast China's Liaoning Province.(30) The Fushun Magnesite Company, the First Sino-Foreign joint venture in Liaoning's mining industry, will be set up by the Liaoning Magnesite Company of Fushun County and a Company in Iwaki, Japan. The joint venture is expected to raise Fushun's annual mining capacity from the present 12,000 tons to 50,000 tons when it goes into operation in 1985. Under a 10-year contract 75 percent of the investment comes from the Chinese side and the rest from the Japanese partner, who will also provide techniques and equipment required for processing, transporting, and packaging.

(2) Foreigner to Run Chinese Factory(31)

A retired engineer (who is a 65-year-old specialist on internal combustion engines) from the Federal Republic of Germany has been named director of a diesel engine factory in Wuhan, Hubei Province, the first time a foreigner has been hired to run a Chinese, state-owned enterprise since the founding of the People´s Republic. The Wuhan Diesel Engine Factory is a medium-sized enterprise with a staff of nearly 2000. It produces 20,000 diesel engines annually. The new director is determined to double the current year´s output of diesel engines in a very short time. Soon after his arrival, he wrote a 50000-word report on ways to renovate the plant. Now this factory is already increasing production.

3.4. Internal Policy

Policy and tactics are the life of the country; every people, especially leading groups at all levels, must give them full attention and must never on any account be negligent.

The general policy and general line of every country as well as various specific policies and specific lines for developing science and technology are formulated by the country´s government. These policies, of course, will affect innovation within the whole country. In addition, every unit (scientific research institute, university, company, firm, etc.) may also formulate its own specific policies for developing science and technology or encouraging various creative activities. These policies will affect innovation within the whole unit, named internal policy. In this sense, units have their own internal policies, such as MIT´s (Massachusetts Institute of Technology) policy, GIT´s (Georgia Institute of Technology) policy, SIC´s (Shanghai Institute of Ceramics) policy, and so on. The characteristics of these internal policies are as follows:

(1) Generally speaking, they should be consistent with the general policy of their own country. They are details added to the general policy.

(2) They have more flexibility and are more suited for every specific unit.

(3) They can be formulated or revised at any time by the unit itself. The following are some examples.

3.4.1. Promotion Policy

Those who have made an important contribution to innovation should be promoted first. At present in China many units have formed some specific policies to promote exceptionally outstanding young people or to recruit talented people without overstressing qualifications from primary level position to high level position, such as from assistant professor to full professor, from technician to chief-engineer, or from group leader to general manager or director of unit.

3.4.2. Reward Policy

Reward policy (including material reward and moral encouragement) is an important policy area. It can further encourage people to be creative in the future.

Those who have made important contributions to innovation and have gained merit should be rewarded. Most units have their own reward policies. The distribution of money prizes should fully reflect the differences between creative contribution to the substantive features of the innovation and responsiblity only for routine affairs, the diligent and the lazy, the good and the bad, more work and less work, mental and manual, complex and simple, leadership and followership, skilled and unskilled, heavy and light work, and so on. We should prevent equalitarianism on the distribution which has long been in some Chinese people's mind.

3.4.3. Other Internal Policies

Those who have made important contributions to innovation may be rewarded with better conditions, such as working conditions (more project funds, good laboratories, big offices, etc.), living conditions, free tickets for travel, and so on. These can be named a working condition policy, living condition policy and welfare policy, etc.

3.5. Organizational Form (32-34)

Organization is the grouping of people and functions to accomplish specified objectives. It is based on a division of labor and a delineation of activities for administrative purposes. Whenever the pursuit of an objective requires the realization of a task that calls for the joint efforts of two or more individuals, organizations are formed. Human resources are organized to show functional interrelationships indicating responsibility and authority, and to establish communication. Organizations are composed of individuals and groups of people. Every country has its own organizational form. An organizational form may be a company, factory, university, scientific research institute, etc. It may also be a department, an office, or a subgroup within a large unit. Usually, organizational forms, personnel in organizations, and their functions are not static. They are developed around the concept that a complex task can be subdivided into simpler components by means of division of labor. Therefore, they must be continuously regrouped and redefined to cope with dynamic operational conditions. Each organization should develop its structure consistent with its internal characteristics and the relationships with its environment. The design of a structure to attain organizational goals should be in accord with two primary criteria:

(1) Organizational forms should help to speed up free information flow, to speed up the innovation process within organizations, and to make the necessary transitional adjustments to stimulate innovation. In this case, talented scientists and engineers can work creatively.

(2) Organizational forms should be established in accordance with the principles of streamlining, unification and efficiency, helping to raise the competence of their functionaries.

The major organizational forms we may encounter are discussed as follows.

3.5.1. Functional Organization

One objective of an organizational form is to divide the total task into specialized pieces. Functional form is structured around the inputs required to perform the tasks of the organization. Typically, these inputs are functions or specialties such as: finance, marketing, production, engineering, research, development, and personnel etc. This form is more centralized and tends to develop highly qualified technical skill. But most decisions that involve multiple functions or skills can only be resolved at the top level.

3.5.2. Divisional Organization

The divisional form is structured according to the outputs generated by the organization. The most common distinction of the outputs is in terms of the products delivered, such as single crystal division, glass division, electronic ceramics division, high temperature structure ceramics division, inorganic coating materials division, etc. However, other types of outputs could serve as a basis for divisionalization, such as projects and programs. Also, market, clients, and geographical locations could serve as criteria for divisionalization.

This form is more decentralized compared with the functional organization. Many decisions can be resolved at the divisional manager´s level, preventing an overburdened top hierarchy. Under both the functional organization and the divisional organization, a person usually has only one boss.

3.5.3. Matrix Organizations

Unlike functional and divisional organizations, which are structured around one central design concept, matrix organizations are structured around two or more central design concepts. The implementation of a matrix structure requires properly designed managerial support systems and people adequately sensitized to the matrix environment. Under the matrix organizational form a person has two (or more) bosses.

Galbraith and Nathanson(35) identify some of the characteristics they judge important for successful development of a matrix climate: the adoption of a multi-dimensional profit reporting system consistent with the matrix design concepts; the establishment of a reward structure leaning toward total corporate profitability; the development of career paths based on multi-functional, multi-businesses and multi-country experiences; and, most importantly, a basic change in the role of the top executive. He must balance the views emerging from different dimensions, act in a more participative manner, develop a judgment for priorities, and be prepared to act as an arbiter in conflicting situations.

3.5.4. Hybrid Organization

The basic organizational forms (functional, divisional, and matrix) presented previously are important design anchors; they have been extensively tested and studied. In fact, all of these organizational forms are pure models, abstractions of a more complex reality. In practice, the structure of organizations stems from more than one of these pure models. Most organizations present combinations of these three archtypes resulting in what we designate as a Hybrid organization. For example, most divisional organizations have a number of functional specialties centralized at the corporate level. Vancil(36) sampled around 300 divisionalized corporations and reported the following percentages of firms have decentralized functions.

Administration	54 %
R & D	64 %
Manufacturing	70 %
Distribution	79 %
Sales	82 %

As we have already indicated, there is a pervasive character of these organizational forms that differentiates the resulting management style. An organizational form in a real case is usually a hybrid of the basic archetypes, and the challenge of organizational design is to seek a proper balance among these three alternatives to respond more effectively to the performance of the organizational tasks. J. W. Lorsch and P. R. Lawrence(37) investigated two plastics companies (Rhody and Crown) which were prominent in their industry and chosen to show similarities and contrasts in their organizational approach to product innovation. The conclusion was that because the Rhody organization achieved both greater specialization and more effective coordination than the Crown company does, the former obtained more innovations than the latter. At Rhody, new products developed in the last 5 years have accounted for 59 % of sales, whereas at Crown, the figure is only 20 %, or just about one-third of Rhody´s.

3.5.5. Work Group or Scientific Team

All of the basic organizational forms mentioned above are structured at the corporate (university, institute, unit) level. In fact, in most scientific laboratories R & D work is carried out by teams (or groups) of scientists and engineers. Therefore, the scientific team is also one of the more common forms in a scientific research institute. It is a sub-hierarchy organization. How does one establish a work group or scientific team which is reasonable when both personnel structure and specialty become an important thing? Why are some teams often cited consistently as being more innovative than others in their R & D work within a given organization? What factors distinguish these more innovative from less innovative R & D teams? Some papers have considered factors such as diversity of team members, group age, characteristics of the supervisor,and especially characteristics of the interaction among team members.(19,p.240;38-40)

R. Katz and T. J. Allen(41) examined the relationship between project performance and the relative influence of project and functional managers in 86 R & D teams in nine technology-based organizations. Performance relationships were investigated for three areas of influence within the project team and for influence in the overall organizations. Analyses show higher project performance when influence over salaries and promotions is perceived as balanced between project and functional managers. Performance reaches its highest level, however, when organizational influence is centered in the project manager and influence over technical details of the work is centered in the functional manager.

Work groups can be designed as long-run forms for long-range planning (more than 5 years) or short-run forms in accordance with work goals and objectives.

3.6. Scale of Unit (Size)(42)

3.6.1. Advantages and Disadvantages based on Size of the Unit

This issue is closely connected with the advantages and disadvantages resulting from the size of the unit. Let us briefly analyse that.

Generally speaking, there are both advantages and disadvantages based on organizational size. Actually, innovations take place both in large and small organizations. Large organizations, especially those operating internationally, have extensive markets and extensive resources. They also have a reservoir of technical people operating from different international locations. They enjoy an advantage where large numbers of different specialists are needed to solve a problem or extensive instrumentation is essential. This gives them access to skills and knowledge not available to a localized operation.

However, large organizations have some inherent disadvantages relative to active innovation. They tend to be conservative and adopt an evolutionary product, as distinct from a revolutionary product approach, unless extreme competition forces a change in operational philosophy, especially in China. Additionally, they are complex, with so many operating strategies that it may take a long time for an innovative idea to work its way through the system to ultimate approval and implementation. This can be discouraging and dampen the enthusiasm of people seeking to introduce new innovations.

There are also advantages and disadvantages in small organizations relative to pursuing innovational objectives. Probably the greatest advantage of the small organization lies in flexibility, concentration (usually one-boss-rule), motivation, low costs, lead-time in developing work (from speed in decision), and internal communications. They are generally extremely responsive to innovative ideas. However, they also encounter operational environmental difficulties, such as limited managerial, financial, or technical resources, sometimes trouble coping with government regulations, and lack of specialist management expertise. They often are geared to a single technology or product which may lead to a make-or-break situation. Another serious disadvantage is limited access to the market. Table 6 shows comparative advantage of types of firms in instrument innovation.(42,p.139)

3.6.2. Bring the Superiority of Large and Small Organization into full Play

As noted above, innovation can take place both in large and small organizations. Table 7 shows percentage of innovations in each firm size category for each five-year period. The key task here is how we can bring the superiority of the large and small organizations into full play and get more innovations under the given conditions. Some empirical results may be summed up as follows:

(1) Most statistical materials identify the size of the firms as measured by total employees: those with less than 1000 emplyees are small firms; with 1000 to 9999, medium-sized firms; with more than 10,000 (10000 to 24999, 25000 or more), large firms. Other analyses have defined "small firms" as those with fewer than 200 employees (see Table 7).

(2) The large organizations enjoy some advantages in extensive

Table 6. Comparative Advantage of Types of Firms in Instrument Innovation

Innovation process	*Established large firm*	*Recent small firm on second or subsequent products*	*Entrepreneur, first product*
Motivation to innovate	3	1—	1
Ability to have or develop own knowledge, technology	1	3	1
Cost advantages, using outside knowledge	2	3	1
Resources available to penetrate market	1	2—	3
Resources for new product development	1	3	1 or 2
Advantage in costs and speed of prototype and early model manufacture	3	1—	1
Flexibility to adopt new product or technology	3	2	1+
Cost advantage, large series production and marketing	1	2—	3

1 = highest comparative advantages, 3 = lowest comparative advantages

Source: C. Freeman (42,P.139)

Table 7. Percentage of Innovations in Each Firm Size Category for Each Five-Year Period

No. of employees	*1945–9* %	*1950–4* %	*1955–9* %	*1960–4* %	*1965–9* %	*1970–4* %	*1975–80* %	*Total* %
1–199	16.0	12.0	11.0	11.0	13.0	15.0 (11.0)	17.0 (12.0)	14.0 (12.0)
200–499	9.0	6.0	8.0	6.0	7.0	9.0 (7.0)	7.0 (6.0)	7.0 (7.0)
500–999	3.0	2.0	7.0	5.0	5.0	4.0 (4.0)	3.0 (3.0)	4.0 (4.0)
1,000–9,999	36.0	36.0	25.0	27.0	23.0	17.0 (19.0)	14.0 (13.0)	23.0 (23.0)
10,000 and over	36.0	44.0	50.0	51.0	52.0	55.1 (59.0)	59.0 (66.0)	52.0 (54.0)
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. of innovations	94	191	274	405	467	401	461	2293

Note: Numbers between brackets for the periods 1970–4 and 1975–80 are the weighted percentage contributions, assuming the same sectoral mix as in the period 1945–69.

Source: J. Townsend *et al.*, *Science and Technology Indicators for the UK: Innovations in Britain since 1945*, Science Policy Research Unit, Occasional Paper No. 16, 1982.

resources, extensive market and technical forces, and have played a critical part in some types of innovations which usually need more financial support, or more technical forces, and are beyond the resources of the small firms, such as synthetic materials, chemical processes, nuclear reactors, space science, turbine generators, and some electronic systems, etc. Generally speaking, large organizations are normally able to undertake projects of greater size and technological magnitude than projects initiated in smaller companies. An extreme case is the Apollo 11 space program for which more than two million components were required. But even in other more mundane complex engineering products, more than 10000 components may be needed also; such as advanced jet aero-engines, electronic telephone exchanges, large computer systems, nuclear reactors, or some process plants. Some statistical materials(42,p.138;43-44) pointed out that the larger corporations (Bell, GE, RCA, IBM, etc) developed a large share of their key innovations, perhaps as much as half, during the post-war period; that they accounted for more than half the key process innovations; that in Europe and Japan, both the imitation process and the innovation process were dominated to a much greater extent by the large corporations.

(3) The small organizations enjoy their advantages in flexibility, concentration, and communication. They have made some outstanding contributions to innovation such as in xerography, electronics, carpets, textile machinery, paper, lumber, camera, and in scientific instruments in particular. As a generalization, innovation from smaller organizations is apt to involve a simple though advanced technological source.

(4) It may be reasonable to postulate that small firms may have some comparative advantages in the earlier stages of innovative work and for the less expensive but more radical innovations, while large firms have an

advantage in the later stages of innovation and in improvement and scaling up of early breakthroughs. Jewkes and his colleagues(42,p.137;45) have made a strong case for the view that universities, private innovators, and smaller firms have made a disproportionately large contribution to the more radical type of twentieth-century innovations. But this point is not absolute, there are significant differents between industries in the relative performance of small and large firms. In some industries, where both research and development work are often very expensive, large firms predominate in both invention and innovation. So, the organizational size would mainly depend on the nature of relevant science and technology or the type of task at hand.

3.6.3. Some Relationships between Size and Innovation Need to be Further Studied

(1) Project SAPPHO (Scientific Activity Predicator from Patterns with Heuristic Origin) was designed as a systematic attempt to discover differences between successful and unsuccessful innovations. Evidence from this project suggests that in competitive attempts to innovate, size in itself does not affect the outcome very much. Hamberg and Scherer(46-47) found only a weak correlation with size measured in terms of employment or sales, and still less of a correlation between large size firms and research intensity with size measured in terms of assets. User-dominant innovation also showed no statistically significant relationship to size--and thus, presumably, to the R & D potential—of the manufacturing company.(48).

(2) The official statistics of research and experimental development expenditures may not capture research or inventive work which is performed by managers, engineers or other staff when the work is incidental to their

main work. It may be that this part-time amateur inventive work is very productive. Also, small firms may account for a significant proportion of inventions and innovations, much of which may go unrecorded in formal statistics.

(3) Some statistics measure the degree of innovation concentration by size of R & D program, and not by size of firm in terms of total employment, turnover, or assets. The degree of concentration is thus much less marked by size of R & D program. On the other hand, for the major countries some statistics are available on concentration by size of firm, although this classification is not consistent.

Table 8. Share of Small Firms in Innovation and Net Output of Industries Surveyed in UK

1958 SIC MLH Number	*1958 SIC title of industry*	*Per cent share of innovation by small firms 1945-70*	*Number of innovations by small firms 1945-70*	*Number of innovations by all firms 1945-70*	*Per cent share of net output by small firms 1963*	*Value of net output by all firms 1963 (£m)*
471-3	Timber and furniture	39	7	18	49	220
351	Scientific instruments	28	23	84	23	154
431-3 450	Leather and footwear	26	5	19	32	157
335	Textile machinery	23	15	65	21	65
481-3	Paper and board	20	6	30	15	317
339	General machinery	17	18	108	14	409
332	Machine tools	11	4	38	18	100
411-15 417, 419 492	Textiles, carpets	10	6	63	18	670
364	Electronics	8	13	160	8	320
211-29	Food	8	3	38	16	814
381	Vehicles, tractors	4	3	64	5	733
276	Synthetic resins and plastics	4	2	52	12	77
370	Ship-building	2	1	59	10	215
271(1)	Dyes	0	0	22	7	35
272(1)	Pharmaceuticals	0	0	44	12	124
463	Glass	0	0	13	14	96
464	Cement	0	0	18	0[a]	41
383	Aircraft	0	0	52	2	185
321	Aluminium	0	0	16	10[a]	100[a]
311-13	Iron and steel	0	0	68	9	630
101	Coal	0	0	23	0	655
601	Gas	0	0	15	0	216
500, 336 337	Construction, earth-moving equipment and contractor's plant	12	4	33	53	1931

[a] Estimated.

Source: C. Freeman (42,p.142)

(4) In 1970 there were in the United States 466 firms with more than 5000 employees, all of which performed at least some R & D. But many of them had relatively small R & D programs, while some medium-sized firms (1000-4999 employees) had rather large ones.(42,p.132) In some industries even the largest firms perform little or no research, and in others even small firms perform a good deal.

(5) The analysis by branch of industry showed big variations in the contribution of small firms to innovation (Table 8).(49) According to this analysis, industries may be classified into two fairly clear-cut groups:

(a) Those industries in which small enterprises made little or no discernible contribution to innovation. These included aerospace, motor vehicles, dyes, etc.

(b) Those industries in which small enterprises made a fairly significant contribution to innovation. These included scientific instruments, electronics, carpets, etc.

(6) The size and structure of industry and its relationship to problems of monopoly and competition is a problem which has preoccupied economists and managers for a long time. Although there is now a considerable amount of statistical information, the evidence is still incomplete and the measurement problems remain formidable because the relative contribution of large and small firms varies a great deal from industry to industry. Investigations now cannot answer the question of the aggregate contribution of large or of small firms to research and innovation in the economy as a whole. How far is it possible to test systematically the relative contribution of small and large firms to innovation in various industries and the economy generally? This is a question which still calls for effective solution. Prof. E. B. Roberts pointed out(6,p.15) that size contribution is closely related to phase of

technology life cycle: small companies (<$10 million in sales) are the principal contributors to major product and process change in Stage I of a new technology. By the time a technology gets to Stage II and especially III, the mature stage of a technology, the role of small companies no longer is dominant though still important. Instead, large companies (over $100 million in sales) tend to dominate. Precisely the same pattern appears to be taking place in biogenetic technology. This is one method of effective analyses.

4. External Factors

We have discussed above major internal factors affecting innovation. Now let us move to discuss briefly some external factors affecting innovation. Usually, external factors are beyond our control; however, we can influence them, fully use them and adapt to the environmental conditions. Sometimes we may be able to transform external factors and adapt them to meet our needs.

4.1. Environmental Conditions

Differences in environmental conditions (or operational climates) can facilitate or retard innovation. Innovation may be impacted by the technological climate, national policy, and/or other industry characteristics. Figure 7 indicates some of the environmental impacts on innovation.

4.1.1. The Technological Climate

The most fundamental method of work which all people must firmly bear in mind is to determine anything according to actual conditions. Actual conditions here mean objective situations or environmental climates. When

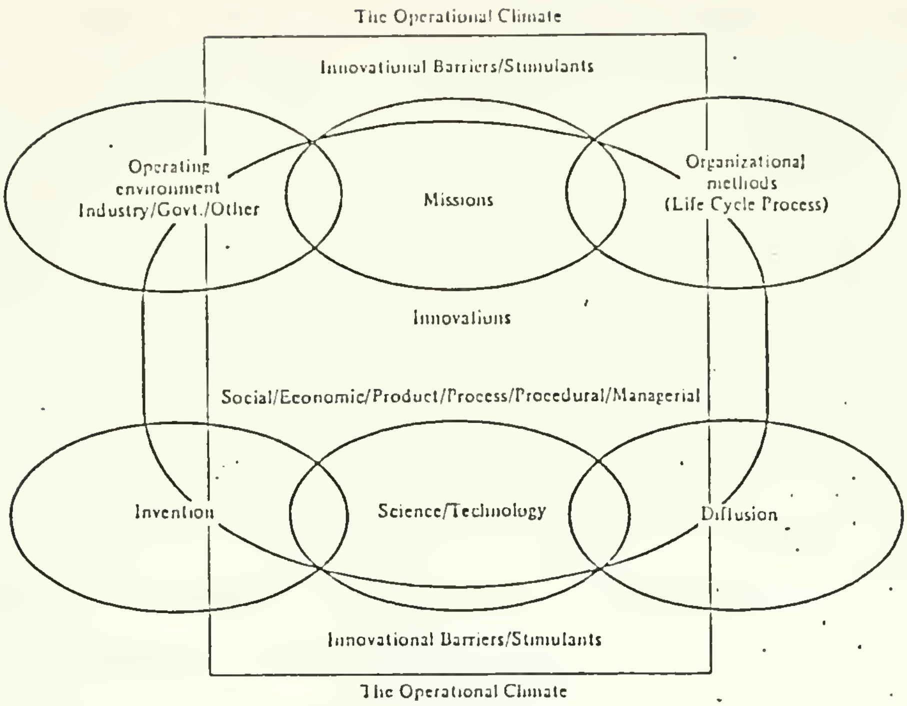


Fig. 7. Environmental Impacts on Innovation
Source: D. D. Roman and J. F. Puett, Jr.(3,P.259)

we study the causes of the mistakes we have made, we often times find that they arose because we departed from the actual situation at a given time and place and were subjective in determining our working policies. If people want to achieve their anticipated results, they must adapt thinking and acting to the given actual conditions. The saying "without stepping outside his gate the scholar knows all the wide world´s affairs", was mere empty talk in past times when technology was undeveloped. But this saying can be valid in the present age of developed technology. Here we would like to emphasize that the saying "was mere empty talk" because of undeveloped technology in the past time and the saying "can be valid" because of developed technology in the present age.

Innovation is also no exception. Successful innovation requires a proper economic, political, and cultural climate, and especially a good technological climate. For example, let us assume you work on high energy physics and have some new ideas to generate an innovation which must use something like an accelerator as a fundamental instrument. You have no way to achieve success unless you get use of the accelerator first. The same thing is true of the electronic computer. Since the first computer was created in 1946, it has been changed from first generation (electronic tube as core device), through second generation (transistor), third generation (integrated circuits) to fourth generation (large scale integrated circuits)—the modern computer. We could not create fourth generation computers in 1946 because no large scale integrated circuits existed for core devices at that time. Obviously, here "accelerator" and "large scale integrated circuits" are technological climates for creating innovations. In other words, if no "accelerator" and "large scale integrated circuits" are included in the environmental conditions, our desires to create these kinds of innovation are merely being "empty thinking".

4.1.2. The National Policy

As earlier indicated, every grass-roots unit can formulate its own specific policies for developing scientific and technological innovation. These policies will affect innovation within the whole unit. Similarly, every country, of course, can also develop important policies for encouraging various creative activities. These policies will affect innovation within the whole country. For example:

(1) Closed door policies to industrialized countries retarded China´s development of science and technology.

In modern society, no country, especially developing countries, can make great progress without learning from other countries. On this basis, our principle should be to learn the strong points of all nations and all countries, to learn from them all that is truly good in science and technology, economics, politics, military affairs, culture and art. We must learn to do economic work and scientific research from all who know how, no matter who they are. We must esteem them as teachers, learn from them respectfully and conscientiously. We must not pretend to know when we do not know. But China´s past policies regarding development of science and technology emphasized Self-Reliance and Arduous Struggle too much and for too long, especially during the Cultural Revolution. In fact, this is one form of the closed-door or Self-Seclusion policies which effectively retard the development of science, technology, and innovation. During the Cultural Revolution a number of scientists, engineers, and innovators were forced out of their laboratories. They had no chance, no time, no place to develop innovations. Damaged by the Cultural Revolution and the policies adopted by the Gang of Four, China´s system of science and technology is often characterized as inefficient. China´s technological level has lagged behind the world´s advanced level by 20-30 years.(50) The "Technology Gap" between China and developed countries was widened rapidly during the time of closed doors.

(2) An open door policy to the world stimulates the prosperity of science and technology.

Since the fall of the radical Gang of Four in late 1976, and particularly in the past two years (1983-1984), the Party Central Committee and the State Council of China have taken a number of policy decisions and issued major directives, stimulating the development of science and technology, especially a step further with the policy of invigorating the domestic economy and opening to the outside world. The modernization of science and technology has been an integral part of China´s current economic development program. China Patent Right´s Agency has been accepting patent applications from overseas since July 1, 1984.(51) China plans sweeping reforms in science and technology, and embraces competition in science and technology as a key to bolster its economy.(52) "Respect for knowledge and talent" is listed in the "Decision On Economic Reform" adopted by the Party´s 12th Central Committee at its Third Plenary Session in October, 1984.(53) That item stressed the need to train and put in place a large number of enterprise directors, managers, chief-engineers, economists, and accountants who are competent at organizing and directing modern production and management within not too long a period. All of these policies will lead to progress in science and technology, to greater initiative of the localities, departments, units, and individuals in making effective use of intellectual resources. In short, these changes in China will have a profound effect on innovation in the future.

4.1.3. Industry Characteristics

In the real world, operational environments vary from industry to industry. Organizational patterns can be studied in a variety of ways, such as by focusing on technologically innovative industries, technologically static industries, new industries, old industries, innovative firms within an industry and noninnovative firms within the same industry. Also industry organizational variances, based on national or cultural characteristics, should have an impact on innovation.

Some industries are likely to be technologically conservative. Innovations in this type of environment tend toward an evolutionary approach--the modified variation of the earlier products. In some industries where technological change is rapid, constant innovation is necessary for growth and survival. Innovations in this kind of environment tend toward a revolutionary approach. Some companies enjoy greater returns from investment in R & D than other companies. The strategy may be imitation rather than innovation. Only successful innovations are copied and risk is minimized. The volatility of the market could also affect the resources devoted to innovation. In areas where the product´s life cycle has become alarmingly compacted, strategy might be directed toward keeping the pipeline full of new products.

In short, different types of environments or industry characteristics will affect innovation. Companies or firms may take aggressive (offensive) innovation strategies or defensive innovation strategies in accordance with the concrete situation which they face.

4.2. Market Incentives

4.2.1. Demand-Pull Innovation

Most successful innovation is need or market stimulated. There´s an old saying that necessity is the mother of innovation. This is "demand-pull" innovation. A comprehensive review of over 2000 case studies of technological change concluded that market factors appear to be the primary influence on innovation.(54) It is estimated that 60 to 80 % of important innovations in a large number of fields have been in response to market demands and needs. Countless innovations fail because no one wants or needs them.(55) Thus, we should strive to find out what consumer or industrial markets need and want, or seek research subjects and research programs from real industries which relate closely to mass production lines. Once we have some good solutions for these subjects, surely they can be put into mass production.

China now takes the following policy: on the one hand, the development of science and technology should integrate with development of economy and progress of the society; the top priority of science and technology should be to improve the development of economy; research on production technology and technology diffusion in industry and agricultural areas should be strengthened; and on the other hand, economic construction must depend on science and technology. The basic aim of China´s current science and technology modernization program is to solve the key problems which act as bottlenecks to industrial, agricultural, and defence modernization. This policy adapts China´s current situation. Under the guidance of this policy new, market-type systems have been introduced. Two important are the emergence of a contract system between research units and factories and, the development of a consulting system between individual scientists and various enterprises or government organizations. In the former case, factories may now solicit assistance from a research institute on a fee basis for a specified period of time. In the latter case, a nation-wide consultancy network administered by the China Association for Science and Technology was formed in January 1983.

4.2.2. Technology-push innovation.

When science and technology develop to a certain extent, R & D can tell marketing that it has developed a new technology that will allow the company to create a new type of product or open a new application. This is technology-push innovation.

Technology-push innovation is generally initiated from the supply side. The technology supplier in such situations innovates and then seeks a new market application. The motivation for technological development is based on market potential and subsequent technology procurement pull. Some points here should be emphasized:

(1) We should bring the current achievements of science and technology into full play.

Usually, the achievements of science and technology are created by one or two firms and are used in some areas first. We should bring these achievements into full play and emphasize achievement-sharing in the whole country (including vertical and horizontal transfers of technology). Competition and inevitable imitation may at times be preferable to achievement-sharing. During this period of time, we can also find some new applications of achievements and spread their scope of application. Four types of "technology transfer" in China now will be encouraged: 1) from research to production; 2) from coastal regions to interior regions; 3) from defence to civilian sectors; and 4) from overseas to domestic users. In some areas, "research-production-unions" and "brain trusts" have been set up to facilitate technology-push innovation.

(2) We must launch research on forecasting demand.

Any kind of innovation must be put in useful form. We should recognize that innovation is never really achieved until it is introduced into and accepted by the actual market. We want not only to know today´s demand, but also to know tomorrow´s need. What are future market trends? To predict the demand for a specific product or service, we must launch research on forecasting demand and fully use its results to guide R & D activity. If the marketing department tells R & D that it should develop a particular type of product, it should be basing its recommendations on its knowledge of what consumers want, what the competition is doing, and what social trends call for the development of a new product, and so on. In this case, once this particular type of innovation succeeds, it will likely be put into mass production sooner.

(3) We should have good supplier's representatives.

There are times when a need can at first be perceived by innovators which is not so apparent to the consumer until the product is introduced. To support this statement, many products on the market that are now considered almost necessities were introduced along with consumer education as to their need. For example, people did not know, at first, that they could have an oven that allowed them to cook a variety of foods in a brief period of time. But now knowing microwave ovens are available, they enjoy the opportunity to use them. Creating a need involves extra effort by the company to persuade the customer of a need for the product benefits before the company can communicate to these customers how the product satisfies the need. It is much easier to satisfy existing needs than to persuade people to want something they don't already want.

In other cases, awareness of a need can be communicated by a customer through a vendor's or supplier's representative. In many industries, suppliers' representatives have technical qualifications and can provide advice to customers. Then innovation is gradually achieved.

(4) The risk for a technological developer is less in the demand-pull situation (because of a committed response to the market) than in the technology-push situation (because of only an anticipation of a market.) Research on West German innovations, for example, found that 70 % of the successes originated from demand-pull factors, whereas 80 % of the failures began with technology-push.(6,56) However, the prospective returns may be much greater in the technology-push situation if the potential market analysis is correct. A technologically innovative strategy can be instrumental in establishing market identification and leadership positions which other firms may subsequently find difficult or

impossible to overcome.(3,p.266)

4.2.3. Users as Innovators

Pioneering studies of users as innovations have been done by Eric A. Von Hippel.(48,57-62) He has analyzed a series of possible patterns for innovations and concluded that many users often become innovators. Also he proposed that both technical and marketing organizations should adjust their strategies to capitalize on the user domination of much innovation. Many of the studies listed in Table 9 demonstrate the significant contributions of the user to innovation.

(1) In some industries, as Table 9 shown, especially in pultrusion processing machinery, scientific instruments, semiconductor and electronic subassembly manufacturing equipment, a heavy percentage of innovations were created by the users of the products and processes. In these areas, user-dominated innovation (innovation inspired and created by a customer rather than a supplier) is far more prevalent than we have previously assumed.

(2) The user as innovator can make important contributions in some ways, such as the user becomes the designer in semiconductors, the user makes what they need in scientific instruments, the user dominates innovations in process machinery, etc. In most "user as innovator" cases studied by Von Hippel, a user came up with the successful solution, implemented it first in his or her own organization for personal use, diffused detailed information on the value of the invention, and made copies available to others on request. Later, a manufacturer produced the innovation in large volume and entered the market.

(3) User-dominated innovation is not equally common in all industries. In some industries, manufacturers develop products responsive

Table 9. Data Regarding the Role of High Need and Lead Users in Product Development

Study	Nature of Innovations and Sample Selection Criteria	Innovative Product Developed By:[a]			
		n	User[a]	Mfg.[a]	Other
Knight (22)	Computer innovations 1944-62:				
	- systems reaching new performance high	143	25%	75%	
	- systems with radical structural innovations (level I)	18	33%	67%	
Enos (23)	Major petroleum processing innovations	7	43%[b]	14%[b]	43%[b]
Freeman (24)	Chemical processes and process equipment available for license, 1967	810	70%	30%	
* Berger (25)	All engineering polymers developed in U.S. after 1955 with >10mm pounds produced in 1975	6	0%	100%	
* Boyden (26)	Chemical additives for plastics: All plasticizers and UV stabilizers developed post World War II for use with 4 major polymers	16	0%	100%	
*Lionetta (27)	All pultrusion processing machinery innovations first introduced commercially 1940-76 which offered users a major increment in functional utility	13	85%	15%	
* von Hippel (28)	Scientific instrument innovations:				
	- first of type (eg. first NMR)	4	100%	0%	
	- major functional improvements	44	82%	18%	
	- minor functional improvements	63	70%	30%	
* von Hippel (29)	Semiconductor and electronic subassembly manufacturing equipment:				
	- first of type used in commercial production	7	100%	0%	
	- major functional improvements	22	63%[c]	21%[c]	16%[c]
	- minor functional improvements	20	59%[c]	29%[c]	12%[c]
* VanderWerf (30)	Wirestripping and connector attachment equipment	20	11%	33%	56%[d]

[a] NA data excluded from percentage computations.

[b] Attribute missing percentage to independent inventors/invention development companies.

[c] Attribute missing percentage to joint user-manufacturer innovation projects.

[d] Attribute to connector suppliers

Source: Eric A. Van Hippel (62,P.27)

to customers needs, this conventional relationship of manufacturer responding to user needs by acting as innovator and product developer is strongly applicable. Table 9 also shows that all innovations in a sample of new engineering polymers and new additives for plastics were developed by manufacturers of those products, revealing no contributions of users.

4.3. Internal and External Communication

Where do good ideas come from? Do they drop from the skies? No. Are they innate in the mind? No. They come from social practice. They come from communication between different kinds of people. In fact, communication processing is the process of gaining information, and information is the essence of any scientific activity. A successful innovation, to a great extent, is the best results of dealing with different types of information. Scientists or engineers must first have information in order to select or decide their subjects (or programs). They must also have other information in order to understand and deepen the problems confronting them. They must have still additional information from either external sources or memory in order to develop possible solutions to their problems. Then they may get a successful innovation.

4.3.1. The Channels of Communication

Three broad classes of information channels are considered and a measurement is made of time spent with literature (books, professional, technical, and other publicly accessible written material), time spent in personal contact outside the lab (vendors, customers, external sources, etc.), and personal contact within the lab (technical staff, company research, personal experience, and experimentation, etc.(32,p.28)). Contacts are especially useful if originated by the persons concerned (the man or his colleagues). Pelz and Andrews(19,p.53)concluded that frequent contacts with many colleagues seemed more beneficial than frequent contacts with just a few colleagues. Similarly, having many colleagues both inside and outside one's own group seemed better than having many colleagues in one place and just a few in the other. So, anything that can be done to promote these forms of contact would be good. One important thing that can be done is to make sure that people working in related areas are aware of each other's activities, interests, and problems. If this condition is met, your professionals can themselves seek the contacts which promise to be useful.

The key communicators in applied research and experimental development groups, especially in the latter, are three different types of gatekeepers: 1) technical—relates well to the advancing world of science and technology; 2) marketing—senses and communicates information relating to customers, competitors, and environmental and regulatory changes affecting the marketplace; and 3) manufacturing—bridges the technical work with the special needs and conditions of the production organization.

4.3.2. The Necessity of Communication

A large number of recent studies show that communication with inside or outside organizational colleagues is strongly related to scientific and technological performance.(19,32,63) Prof. Allen(32) in his book, Managing the Flow of Technology, described more details about the communication system in technology; the importance of communication within the laboratory; communications among organizations; structuring communication networks (including the influence of formal and informal organization, and the influence of architecture on communication). R & D today is a very complex activity. In most cases, the development of new products or processes requires a wide diversity of talents and knowledge. It is seldom that any single individual has all of the requisite knowledge. In the past several years, therefore, interdisciplinary project teams to deal with complex R & D problems have developed. Even such teams, however, seldom have all of the information needed to accomplish a project successfully. It is even rare when the diverse talents, experience, and technological understanding necessary to accomplish an R & D project can be found entirely within the small group of engineers assigned directly to the project. Few, if any, project teams can be entirely self-sufficient. Most R & D projects will therefore require some consulting support from people who are not assigned to them.

The development of a successful innovation also requires multiple ideas for solutions to the multiple technological problems which arise during a project. Both inside or outside the organization communication plays a significant role in problem-solving. Much research on industrial innovation demonstrates that key technical answers to major problems come from outside of the organization where the work is underway. Several studies also point out that for innovations eventually developed within a firm, the sources of initial technical ideas divide between inside and outside origins on about a 2:3 basis.(6,64) These studies also show that personal experiences (ideas that were used previously for similar problems and are recalled directly from memory) and contacts are key sources of information whereas the scientific literature sometimes yields relatively little productivity.

Myers and Marquis(6,65) studied the sources of information for 567 innovations in five industrial fields with 120 firms. They indicated that personal contacts generated a total of 25 % of the solutions, and personal training and experience produced an additional 48 %.

4.3.3. The Possibility of Communication

A very interesting phenomenon is that a series of innovations do not emanate from established companies in established industries due to strong competitive pressures. Synthetic fibers were developed by the chemical industry rather than the textile industry. High-speed ground transportation development has extended from the automobile and railroad industries to the aerospace and electrical manufacturing industries. Instant photography was developed outside the conventional photographic industry. Xeroxing was not a product innovated by the office equipment industry.(3,p.256) The aforementioned illustrations can be supplemented by numerous other examples. These examples show the possibility of communication between different organizations. Even though they work in different fields, they may also have some common language.

But, the need for communication in science and technology is not universal among R & D workers. This is the result from a number of studies at the Sloan School of Management in MIT.(32) Those engaged in basic research will benefit from extensive professional commnication with colleagues in similar work elsewhere because of having roughly the same language and the same goals. In fact, scientists can contribute to each other´s effectiveness. Those engaged in development gain less from such communication. In this case, the gregarious "gate-keeper"—a research worker who is also unusual as an active communicator, not only reaches out to workers in the same field in other organizations but can interpret their work in the context of his own organization´s assignments and needs. Communication with colleagues outside the organization at times may have no effect on the performance of engineers in technical service projects. This may be because research work is so closely coupled to organizational goals that outside inputs are unnecessary. Figure 8 shows the relationships between project performance and communications in different kinds of programs.(66)

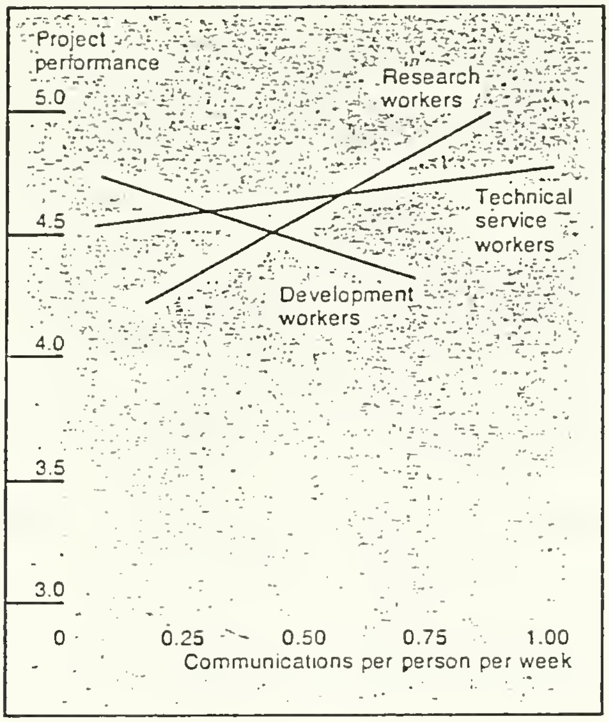


Fig. 8. The Relationships between Project Performance and Communication in Different Kinds of Program
Source: (66)

4.4. Government Role

Government can play an important role in stimulating or enhancing innovation by 1) government's effect on science and technology (government program); 2) the government's stability (political environment); 3) regulation (legislating regulatory measures); and 4) its policies on science and technology (see 4.1.2.).

Government's effects may embody three aspects: 1) organizing large public programs. For example, the placing of a man on the moon and the orbiting of an earth resources satellite are specific accomplishments in United States; 2) engaging in intensified planning for innovative solutions. For example, the Chinese government has given prominence to the eight comprehensive scientific and technological spheres, important new techniques and pacesetting disciplines that have a bearing on the overall situation. These are agriculture, energy, materials, electronic computer, lasers, space, high energy physics, and genetic engineering. The plan calls for concentrating all forces and achieving remarkable successes so as to promote the high-speed development of science and technology as a whole and of the entire national economy; 3) giving financial support to R & D, especially to some specific programs. For example, the U.S. Government has given direct or indirect financial support to space-defence programs for semiconductor and computer R & D.

The political environment can also serve as an innovation stimulant or barrier. A politically unstable government can discourage venture capital especially in high-risk areas. Government regulations can be instrumental in encouraging or discouraging innovation. Legal restrictions and regulations can dampen innovation enthusiasm. A good example is the extremely high tax rate in England which, in concert with high developmental costs and the high risks of innovation, acts as a negative incentive. The Chinese government has set up four kinds of reward regulations in order to encourage the enthusiasm, initiative and creativeness of enterprises and all staff members working in science and technology for innovation: a) The Reward System of Invention-Creation ; b) The Reward System of Heavy Achievement; c) The Reward System of Natural Science; and d) The Reward System of Rationalization Proposal. Since these reward systems were promulgated in China, the number of heavy achievements, innovations, and suggestions has increased annually.

The role of the Japanese government in promoting its domestic advanced ceramics industries is also a good example.(67) Advanced ceramic materials are a relatively new class of high-performance materials with significant potential for future economic impact. They are differentiated from traditional ceramics by their specialized properties. Because of these special properties, advanced ceramic materials are expected to be used increasingly in a number of high-performance commercial applications ranging from heat-and wear-resistant parts to electronic and optical devices. Japan anticipates that the development of an advanced ceramics industry will make a major contribution to some of their most important national goals: 1) Being a natural resource poor nation, the use of advanced ceramics would enable Japan to substitute indigenous for imported raw materials and would also contribute to energy conservation, lowering its dependence on imported petroleum; 2) Superiority in advanced electronic ceramics adds another advantage to their already strong electronics industries; 3) Becoming the world leader in advanced engineering ceramics will directly result in sizable new exports of the products themselves and indirectly add to the value of automotive, machine tool, and perhaps aerospace exports. So all previous Japanese governments have given a vast amount of financial support to R & D for the large-scale advanced ceramic industry. Both the "Sunshine" (alternative energy production) and "Moonlight" (energy conservation) Projects have involved new materials for high-temperature conditions including advanced ceramics. This is why Japan has sustained itself as a world leader in advanced ceramics, accounting for about half of world production, and dominanting the electronic components business, particularly in integrated circuits packaging.

5. Some Suggestions

We have discussed above both major internal and external factors affecting innovation. We hold that the most important problem does not lie in understanding the laws of the objective world and thus being able to explain it, but in applying the knowledge of these laws actively to guide our practical activity and change the real world. If we have a correct theory but merely prate about it, pigeonhole it and do not put it into practice, then that theory, however good, is of no significance. Following are some suggestions about stimulating innovation on the basis of the above analysis.

5.1. Correct Selection of Central Persons

The correct selection of central persons is of fundamental importance to the success or failure of any unit. The saying "it all depends on human efforts" is quite true. Leaders at all levels must give it full attention. Some significant points here are :

(1) "Central persons" does not mean only one or two people

As earlier indicated, successful innovation is a complex process with several stages from generation of the idea to useful form. Corresponding to each stage, there are some qualitatively different tasks to be fulfilled. Each of the several tasks required for effective technical innovation presents unique challenges and must be filled with very different types of people. We should not only have some creative scientists and engineers as central persons, but also some entrepreneurs, project managers, sponsors, gatekeepers, technical problem-solvers, and quality controllers must be treated as central persons. In short, this contingent should consist of qualified personnel in all trades and occupations for the whole chain of effective technical innovation. The situation here is something like the theatrical troupe.

Many technical organizations have failed to be innovative because one or more of these quite different critical functions has been absent. Of course, each type of personnel needs to be recruited, managed, supported differently, offered different sets of incentives, and supervised with different types of measures and controls.

(2) Train Central Persons More Actively

Where are the technical central persons to come from? One main source is from training and upbringing of people within the organization who are working at different positions and have some successful experiences. The Sloan School of Management at MIT provides some programs for that, such as the Management of Technology Program, the Sloan Fellows Program, and the two-week Special Summer Program. The Management of Technology Program is intended for experienced engineers and scientists on a career path requiring increasing responsibility for managing technical activities and technology-based organizations. The two-week Program provides an understanding of the underlying innovation process, and seeks to improve the managerial skills and perspectives of course participants. Practice in the past years have amply demonstrated that these programs offer effective help. After short training supplements the original successful experiences of technical people, a lot of these persons have become central in their enterprises.

The need for central persons in China now is urgent and pressing. A recent survey of 120 key large and medium sized enterprises shows that only 29.3 per cent of their directors and managers have had a college education. Among them only 0.8 per cent majored in economics and finance. Still fewer have attended management schools. Although great efforts have been made in recent years to promote young, middle-aged intellectuals to leading positions, the majority of them were engineers or technicians who did not have management training or experience.(53) We know with pleasure that the Central Committee of the Chinese Communist Party has drawn up plans and taken effective measures to quickly train large numbers of directors (managers) who can successfully organize and direct enterprise production and operations, chief engineers who can strengthen technical management and promote technological progress, chief economic managers who can improve business operations for better economic results, and chief accountants who can strictly uphold financial and economic disciplines, do careful budgeting and exploit new sources of revenue. This is how to create a mighty contingent of managerial and technical talents for economic construction.(68) Another Party Central Committee decision says that more managers should be trained and each enterprise should appoint three "chiefs", who are to be in charge of technology, economic planning and marketing, and accounting.(69) In the past, the role of these three "chiefs" have not been given sufficient importance. Most of the nation´s enterprises have chief engineers, but only 20 per cent have chief accountants, and a mere 10 per cent have economic planning and marketing chiefs.

(3) Send studends or scholars to developed countries

Practical experience over the years shows that sending students or scholars to developed countries is an effective way for improving central persons. The Chinese government has sent about 33000 students (including 7000 financially self-supporting students) to study in more than 60 countries during the past six years. Fourteen thousand (14000) of them have already returned home after completing their courses.(70) This is more than twice the number of students sent abroad over the 28 years before 1979--the year China set about opening to the outside world. The number sent abroad will be increased to 4000 in 1985 from the 3000 in 1984.

There has been a sharp increase in the number of postgraduate students and scholars sent abroad. Together, they constitute 78 per cent of the total number of Chinese studying abroad. In 1978, they made up just 10 per cent.

In fact, sending students abroad is one way to import "intelligence." Tapping the intelligence of people is more important than importing advanced techniques and equipment. We are sure, most of these students will become central persons in different fields in the near future.

The advantage of sending experienced experts for short-term study abroad has been also improved their ability to absorb useful knowledge needed in their professions and to apply it to their work after returning home.

5.2. Timely Establishment of an Industrial Liaison Program

The organized "innovation process" requires not only the effective management of research, development, and engineering (R D & E), but also imaginative management of the linkages among the stages of the whole innovation process (R & D, engineering, production, and marketing). That is, there is an interface between each stage of innovation. Historically, in the United States, over $80 billion are spent annually on R D & E alone, and many times that amount is devoted to the transfer of R D & E results to the market or into the production process. European R D & E expenditure in government and industry are comparable in magnitude.(71) Yet many managers of these activities have usually advanced as a result of technical expertise alone and often lack management knowledge.

We should make organizations operate more effectively. MIT in the United States has set up the Industrial Liaison Program in order to strengthen relationships between the university and industry. The program offers a set of services that brings MIT technical and managerial advances to member companies systematically and continually through on-campus visits, a symposium series, a program of short courses and, through an extensive publications collection. Over 300 member companies and government organizations have access to ongoing research at MIT throughout the year. This relationship has enabled MIT to make major contributions to industrial development in the U.S. and other countries over the years, and it is of critical importance to innovation and technology transfer in the future. The program´s robust growth since 1948 to its present membership on four continents amply demonstrates its value to members. Some organizations consider membership their most effective single investment in research, science and technology. This is a successful experience that should be imitated.

Similarly, China has found a new and effective way to combine technological and economic development. The method is to hold technical trade fairs at which scientific institutes, colleges, factories, and individual innovators swap research results and join in tackling complex problems. This practice has helped integrate research work with economic construction and has encouraged the initiative of scientific personnel.(72) People can come to such fairs to seek or offer technical services, contracts, demonstrations, information and new products. Asking or bidding for solutions to difficult problems, recruitment of skilled people, import of technology and formation of firms combining technology, production and trade can also be done at such fairs. China has sponsored 241 large technical trade fairs since 1980. In addition, more than 1000 scientific and technological and exchange centres have been established in different parts of China in order to strengthen relationships between R & D and industry. The consulting service centre of the Shanghai Science and

Technology Association was established in 1983 with the approval of the Shanghai Municipal Government. Members of the centre include 108 institutes or associations of natural science in the city of Shanghai and associations of science and technology in 12 districts and 10 outlying counties.(73)

5.3. Conscientious Arrangement of Three Kinds of Research

According to the measurement of scientific and technical activities, R & D can be divided into three categories:

(1) Basic Research

Basic Research is theoretical or experimental work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.

(2) Applied Research

Applied Research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.

(3) Experimental Development

Experimental Development is systematic work, drawing on existing knowledge gained from research and/or practical experience, that is directed to producing new materials, products and devices, to installing new processes, systems and services, and to improving substantially those already produced or installed.

All of these three categories comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including the knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. They supplement or complement each other. They may be done in order of importance and urgency, but we should never do one thing and neglect another. Most people know that applied research and experimental development can contribute greatly to innovations and industries. However, it is important that we do not undervalue the role of basic research. It can also make contributions to successful industrial innovation. The most widely held view is that there exists a pool of fundamental knowledge available to all innovators. They draw freely from the pool and utilize that knowledge to assist in the development of their innovations. It follows then that to maintain vigorous innovative action there must be a continuous flow of new knowledge into this pool which is available to all.

W. C. Fernelius and his colleagues(74) analyzed seventy-eight innovations which had become commercial "successes" since 1965 in 22 different industrial areas. In 87 per cent of the cases, the basic research leading to commercilization was financed and performed by the reporting company. Also, the British Government has focused heavily on supporting R & D in basic fields. This orientation has led the British to make major contributions to science and technology—in particular to areas of "big science" such as defence, nuclear energy, and space.(75)

Basic research has also contributed to innovation in China. In 1982 the State Science and Technology Commission awarded to the Shanghai Institute of Ceramics, Chinese Academy of Sciences, a first class reward for innovation for a new type of inorganic non-metallic material. This material was discoverd as a result of basic research. The Chinese government still supports basic research and major scientific projects on a competitive basis. Institutes engaged in this type of research will now have to compete for money from national foundations.(52)

In conclusion, it is important that these three kinds of research be conscientiously arranged. As for the ratio of basic research to applied research and experimental development, different countries (different times also) have different situations. Table 10 shows respectively the annual funds in the United States for basic research, applied research, and experimental development during the period of 1974-1984. From Table 10, we see that the ratio is around 1 : 2 : 6 for the years 1983-1984 (here the ratio is calculated according to funds, but also calculable according to the number of projects or people).

Table 10. The Annual Funds in United States for Basic Research, Applied Research and Experimental Development(1974-84)

$ Billions, current												Annual change	
	1984[a]	1983[a]	1982	1981	1980	1979	1978	1977	1976	1975	1974	1983-84	1974-84
Basic research	$11.9	$10.6	$ 9.9	$ 9.2	$ 8.1	$ 7.3	$ 6.4	$ 5.5	$ 5.0	$ 4.6	$ 4.2	12%	11%
Applied research	21.4	19.9	18.4	16.9	14.1	12.4	10.8	9.7	9.0	7.9	7.2	8	12
Development	63.7.	57.2	52.0	45.8	40.5	35.3	30.9	27.5	25.0	22.7	21.4	11	12

[a] Estimated. Source: National Science Foundation

$ Billions, constant (1972)												Annual change	
	1984[a]	1983[a]	1982	1981	1980	1979	1978	1977	1976	1975	1974	1982-84	1974-84
Basic research	$ 5.2	$ 4.9	$ 4.7	$ 4.7	$ 4.5	$ 4.4	$ 4.3	$ 3.9	$ 3.8	$ 3.7	$ 3.8	7%	3%
Applied research	9.5	9.2	8.9	8.7	7.9	7.6	7.2	6.9	6.8	6.3	6.3	3	4
Development	26.2	26.5	25.1	23.5	22.7	21.6	20.5	19.6	18.9	18.1	18.7	7	4

[a] Estimated. Source: National Science Foundation

Source: (78)

5.4. Strict Separation of Responsibilities Among Different People

The successful experience of many developed countries shows that every unit must specify in explicit terms the requirements for each work post and the duties of each staff member and must establish various responsibility systems so as to raise the sense of responsibility of all staff members and bring into full play their initiative, enthusiasm and creativeness. The basic principles of this responsibility system are a combination of responsibility, authority, and benefit; the unity of the interests of the state, the collectives and the individuals; and the linking of the income of all staff members with their job performance. This issue can be discussed for several levels.

(1) Separate Government from any Enterprise Functions

Separating government from university, scientific research institute and business enterprise is an effective method in developed countries. We must learn from them respectfully and conscientiously. The functions of government in China for a long time were not separated from those of the university, institute, or any enterprise, which in fact became appendages of administrative organs, and the central and local governments took responsibility for many matters which were not really theirs and at the same time did not do well what they ought to do. This, plus the barriers between different departments or regions and the practice of endless wrangles, increased the difficulties in running enterprises. If this state of affairs were not changed, the enthusiasm of the universities, institutes, enterprises, and other grass-roots units could not be aroused, cooperation, association and competition between units could not develop. The national economy would be bereft of much of the vitality it should possess. In this case, we want to produce more innovations, which is easier said than done.

So, there is a pressing need to conduct reform in line with the principle of separating the functions of government and the functions of enterprise, streamlining administration and instituting decentralization in order to invigorate the enterprises and the national economy as a whole. We must end the longstanding practice of leading organs making enterprises and units completely dependent on them, instead of serving the enterprises and other grass-roots units. Also, we must eliminate such bureaucratic maladies as organizational overlapping, overstaffing, and vague delimitation of functions. The leading organs at various levels will thus be able to orient their work towards promoting production, serving the enterprises and other grass-roots units, and helping build a strong and prosperous country and bring prosperity and happiness to the people.

(2) Separate Central Persons from Common Faculty Functions

Different central persons (all five kinds of staff have their own central persons) have different functions and responsibilities. We must separate their responsibilities from each other. Usually, central persons are in charge of over-all responsibility in their groups and must take into account the whole situation around their tasks. They must put different tasks in their proper order and be good at being a "squad leader". A good central person should keep a firm grasp on his central task and at the same time, around the central task, he should unfold the work in other aspects, and rely on his "squad members" and enable them to play their parts to the full.

Both central persons and common university faculty have their own tasks and responsibilities, which never replace each other.

(3) Separate Faculty from Supported Staff Functions

Many countries in the world have established secretarial support system, in which a secretary works for a director, or for a central person, for a professor, an engineer, and so on. Practice over the years has proven that this is an effective way. A good secretary can deal with a lot of routine affairs for faculty. In this case, faculty can concentrate their energy on doing more important things which they can do best. A common saying goes, "with all its beauty the lotus needs the green of its leaves to set it off." It is quite true. We should learn from this advanced country experience. In China, many famous professors, scientists, and engineers have no support staff. Not just a few core members of science and technology organizations have reported to the higher level leadership group that they must take care of many secretarial matters themselves during the whole process of scientific activity—from selecting programs, to deciding and implementing solutions, to purchasing and moving instruments, to dealing with any routine affairs. Sometimes, they also spend a lot of energy handling contradictions among the people thus wasting much time, and time is very valuable. There is a proverb in China: "Spring determines the plan for the year; morning determines the plan for the day," that is, no more time can be wasted. They appeal many times that scientists must do scientists' work. We should take full advantage of their professional knowledge and skill. But this situation is still serious today. Many support people would like to be promoted to scientist or engineer positions and many scientists can not effectively do research work because of dealing with secretarial matters. In fact, this is a form of the practice of "eating from the same big pot" prevailing in the relations of the staff members to their units. We must turn round this situation soon and end this situation forever. It should be noted that the person who graduated only from elementary or middle school is not as qualified or knowledgeable regarding electrical matters as the one who graduated from college in electrical engineering. But, both are valuable people to the country—doing what they know how to do best.

5.5. Deliberate Seizing of Any Small Opportunity for Innovation

Technology development is much more evolutionary and much less revolutionary or breakthrough-oriented than most people imagine. It is important to realize that the result of a series of evolutionary steps in technology, together amounting to a large improvement, is just as vital as achieving a technological revolution. This is illustrated by the history of technology development. Innovations of the steam engine and the computer are two good examples.(76)

The popular notion of the development of the steam engine includes the story of how James Watt was in his mother´s kitchen, the kettle boiled, steam came out, and J. Watt realized the tremendous power of steam and later invented the steam engine. This story has nothing to do with reality. The true origin of the steam engine is much more interesting. The hitory of the steam engine may be considered to start in about 1680 with the famous Dutch physicist C. Huygens, who was trying to develop an engine based on gunpowder (he would have liked to create a vacuum with it but did not succeed), through D. Papin´s effort (an assistant of Huygens, who used steam to create a vacuum and built a small-scale engine´s model in 1690), T. Svery´s effort (an England scientist, who made the first full-scale working steam engine in 1698, but had a number of problems with it), T. Newcomen´s effort (a plumber, who came up with the first reliable and widely used steam engine for pumping water out of coal mines in early 18th-century England, basically a blown-up version of the Papin engine), T. Smeaton´s effort (who, around 1767, made a better engine and raised the duty--a measure of the goodness and efficiency of engines—from 4 to 7-12), finally, around 1775, J. Watt appeared and put it into the energy source that changed the world (of course, later in his life, steam engine improvements continued). So, the successful innovation of the steam engine was the result of a series of evolutionary steps, and the cumulative effect of small improvements. The successful innovation of the computer follows a similar pattern.

Real breakthroughs do however occur; they are rare and stunning events. The more common course of technological evolution is steady, year-to-year improvement, and in the end are very much revolutionary.

At times breakthroughs, such as the transistor, recombinant DNA, and the atomic bomb, are the results of the introduction of new knowledge coming from quite different areas. The transistor was the result of long, patient, and mainly undirected basic scientific work that led to a sufficient understanding of solid-state physics to make it possible. Recombinant DNA—should it prove to be successful in chemical processing—will be the introduction into a new field of the accumulated knowledge about the fundamentals of molecular biology. Similarly, the atomic bomb was not the evolutionary outgrowth of explosives but represented the introduction of knowledge about the structure of the nucleus into the field of weaponry.

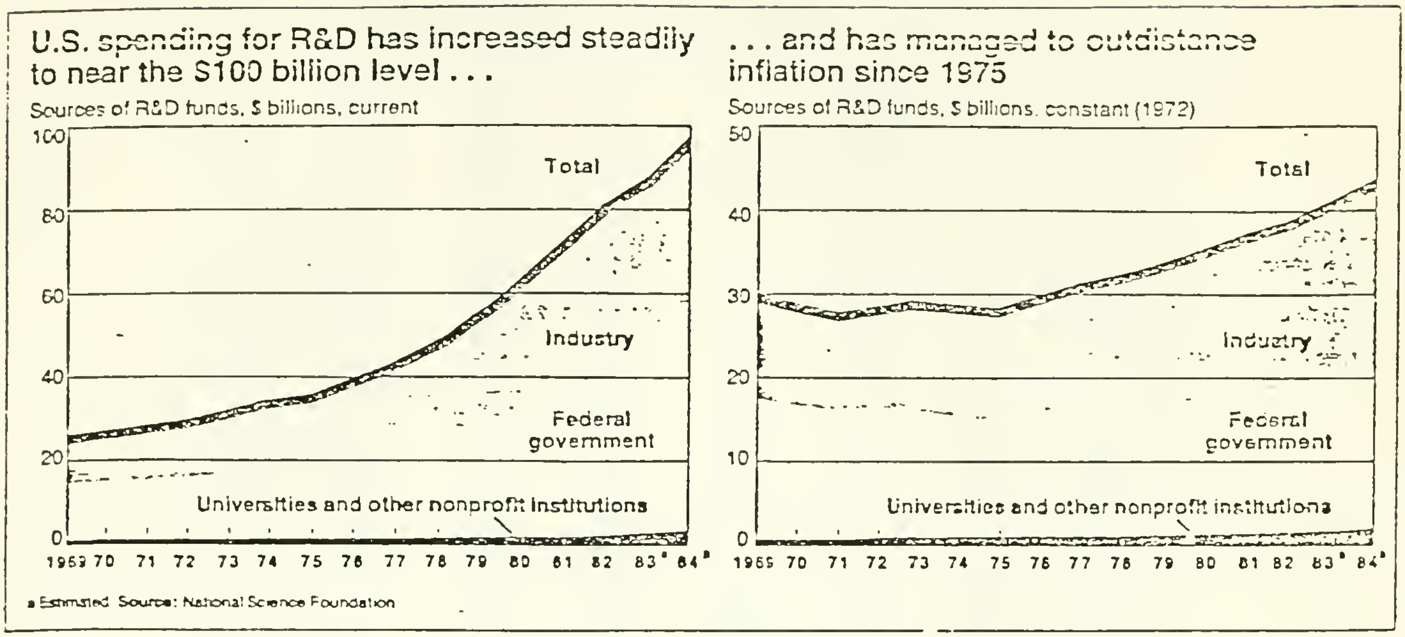
In modern industries, many enterprises take this philosophy of developmental innovation as one of their main strategies and thus make themselves full of vigour and vitality. 3M (Minnesota Mining & Manufacturing Co.) may be a good example.(77) The technical strategy of 3M was to start more little businesses and more little businessmen. Now 3M makes a lot of new products such as tranparent tape, reflective signs for highways, water and stain repellent chemicals for clothes, carpets that athletes play on, slide projectors, magnetic tape, sandpaper, tape recorders, cook-in bags for food, floor-polishing pads, copying machines, adhesives, electrical insulating tape, and hair-setting tape.

5.6. Gradual Increase of Scientific Research Funds

R & D funding is one of the necessary conditions for scientific activity. It may come from the government, industry, and/or other sources. The experience of developed countries has indicated that industry maintains its lead as the largest source of R & D money although expansion in all sectors is slashed by inflation. Industry in the U.S. spends about three fourths of all dollars for R & D, with a big gain in spending in

1984 in constant dollar.(78) Total spending in the U.S. on R & D, according to the National Science Foundation, is about $97.0 billion in 1984, an increase of 11 % over the 1983 level. In constant dollars, this constitutes a gain of 6 %, well above the 4 % average annual increase in R & D spending over the period of 1974-1984 and the biggest annual gain since the 1960s. U.S. spending for R & D has increased steadily to near the $100 billion level (Figue 9(a)) and has managed to outdistance inflation since 1975 (Figue 9(b)). Table 11 shows national expenditures for performance of R & D as a percent of gross national product (GNP) by country: 1961-1983. From Table 11, we can clearly see that: 1) the U.S. and U.S.S.R. pay much attention to R & D funding—their ratio of R & D expenditures to gross national product is more than 2 %. This is one reason why they have highly advanced science and technology in many areas today; 2) this ratio for other developed countries is between 1 % and 2 %.

China currently has no systematic statistical materials about the ratio of R & D expenditures to gross national product. Although great efforts have been made in recent years to increase R & D funding, some people know this ratio in China is still less than 1 %. We should strive to do careful budgeting and exploit new sources of revenue for R & D funding.



(a) (b)

Fig. 9. U. S. Spending for R & D
Source: (78)

Table 11. National Expenditures for Performance of R & D as a Percent of Gross National Product (GNP) by Country: 1961-1983

Year	France	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	Ratio of R&D expenditures to gross national product¹					
1961	1.38	NA	1.39	2.45	2.73	NA
1962	1.46	1.25	1.47	NA	2.72	2.64
1963	1.55	1.41	1.44	NA	2.86	2.80
1964	1.81	1.57	1.48	2.29	2.96	2.87
1965	2.01	1.73	1.52	NA	2.90	2.85
1966	2.06	1.81	1.46	2.31	2.89	2.88
1967	2.13	1.97	1.52	2.29	2.89	2.91
1968	2.08	1.97	1.60	2.25	2.62	NA
1969	1.94	2.05	1.64	2.22	2.72	3.03
1970	1.91	2.18	1.81	NA	2.63	3.23
1971	1.90	2.38	1.85	NA	2.48	3.29
1972	1.86	2.33	1.86	2.05	2.40	3.58
1973	1.76	2.22	1.90	NA	2.32	3.66
1974	1.79	2.26	1.97	NA	2.29	3.64
1975	1.80	2.38	1.96	2.05	2.27	3.59
1976	1.77	2.29	1.95	NA	2.27	3.55
1977	1.76	2.31	1.93	NA	2.23	3.46
1978	1.76	2.31	1.96	2.13	2.23	3.47
1979	1.81	2.59	2.06	NA	2.27	3.44
1980 (prel.)	1.85	2.65	2.18	NA	2.38	3.67
1981 (prel.)	1.97	2.68	2.36	NA	2.45	3.66
1982 (est.)	NA	NA	NA	NA	2.58	3.65
1983 (est.)	NA	NA	NA	NA	2.65	NA
	R&D expenditures (national currency in billions)²					
1961	4.5	NA	275.5	0.68	14.3	NA
1962	5.4	4.5	319.3	NA	15.4	5.2
1963	6.4	5.4	368.3	NA	17.1	5.8
1964	8.3	6.6	438.1	.77	18.9	6.4
1965	9.8	7.9	508.6	NA	20.0	6.9
1966	11.0	8.8	576.6	.89	21.8	7.5
1967	12.2	9.7	702.5	.93	23.1	8.2
1968	13.1	10.6	677.5	.99	24.6	9.0
1969	14.2	12.2	1,064.7	1.05	25.6	10.0
1970	15.0	14.8	1,355.5	NA	26.1	11.7
1971	15.6	18.0	1,532.4	NA	26.7	13.0
1972	18.3	19.2	1,791.9	1.31	28.5	14.4
1973	19.8	20.5	2,215.8	NA	30.7	15.7
1974	23.0	22.3	2,716.0	NA	32.9	16.5
1975	26.2	24.6	2,974.6	2.15	35.2	17.4
1976	29.8	25.7	3,320.7	NA	39.0	17.7
1977	33.2	27.7	3,551.3	NA	42.8	18.3
1978	37.7	29.9	4,045.9	3.51	48.2	19.3
1979	44.1	36.1	4,583.6	NA	55.0	20.2
1980 (prel.)	51.0	39.3	5,246.2	NA	62.7	22.3
1981 (est.)	61.0	41.3	5,982.4	NA	72.1	23.4
1982 (est.)	NA	NA	NA	NA	79.0	24.0
1983 (est.)	NA	NA	NA	NA	86.5	25.5

(continued)

Table 11. (Continued)

Year	France[3]	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	Gross national product (national currency in billions)					
1961	328.4	331.4	19.552.8	27.5	524.6	NA
1962	367.2	360.5	21.659.5	28.9	565.0	197.2
1963	412.0	382.1	25.592.1	30.8	596.7	206.8
1964	456.7	419.6	29.661.9	33.5	637.7	223.2
1965	489.8	458.2	33.550.2	36.0	691.1	242.1
1966	532.0	487.4	39,452.0	38 4	756.0	260.1
1967	574.8	493.7	46,175.6	40.5	799.6	262.0
1968	630.0	535.2	54.689.2	43.8	873.4	NA
1969	734.0	597.7	64.850.8	47.1	944.0	329.6
1970	762.0	679.0	75.091.6	51.6	992.7	362.2
1971	873.1	756.0	82,725.8	57.8	1,077.6	394.8
1972	961.3	827.2	96,424.0	63.9	1.185.9	401.8
1973	1.121.3	920.1	116.636.3	74.2	1,326.4	429.4
1974	1.284.4	986.9	138.044.6	84.3	1,434.2	453.1
1975	1,452.0	1,034.9	151,797.0	105.2	1.549.2	471.8
1976	1,677.8	1,125.0	170.290.0	125.7	1,718.0	498.6
1977	1.885.0	1.200.0	188.804.3	143.2	1.918.3	528.8
1978	2,141.0	1.290.7	206,762.5	164.6	2,163.9	556.8
1979	2,439.0	1,395.3	222,043.1	191.1	2,417.8	587.9
1980 (prel.)	2,759.0	1,484.2	240,647.0	223.0	2.633.1	607.7
1981 (est.)	3.094.0	1,543.1	253.811.2	NA	2.937.7	640.1
1982 (est.)	NA	NA	NA	NA	3,057.6	658.1
1983 (est.)	NA	NA	NA	NA	3,262.0	NA

[1] Calculated from unrounded figures.

[2] Gross expenditures for performance of R&D including associated capital expenditures except for the United States where total capital expenditure data are not available. U.S. estimates for the period 1972-80 show that the inclusion of capital expenditures would have an impact of less than one tenth of one percent on the R&D/GNP ratio.

[3] Gross domestic product.

NA = not available.

NOTE. The latest for each country data may be preliminary or estimates. The figures for West Germany increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977.

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