Attachment 15

March 1977

From Invention to Commercialization

Evidence doesn't support popular notion that technological progress is accelerating

BY L. EDWARD KLEIN*

INTRODUCTION

The general purpose of this brief review is to present some basic observations about the time required for the so-called technical innovation process (the process of translating technical knowledge and invention into economic reality). The use of the word "innovation" is important because the literature today seems in general agreement that whereas *invention* is getting the idea, *innovation*, or development, is overcoming all the hurdles to its economic use.[1] Jewkes[2] prefers the word "development" rather than "innovation" and points out that new "inventions" are sometimes needed when further "development" is blocked because existing technology is inadequate. He points out that drawing too sharp a line is as foolish as trying to determine whether twilight is night or day, yet he insists there is a fundamental distinction between "invention" and "development" (or innovation).

The *specific* purpose of this review is to provide a fact basis on this issue so that various national policies on the length of protection for patents can be intelligently assessed.

A WORKING HYPOTHESIS

This paper will provide further support for a "proposition" put forward by Bright several years ago that *the full process of technological innovation usually takes upwards of 10 years, and a quarter of a century is not an uncommon time.*[3]

In stating his case Bright used the word "proposition" rather than "law" because there are exceptions and sometimes important ones. Nevertheless "proposition" does assert some force and permits a reasonable degree of confidence for the establishment of policy.

It is also useful to use the word "radical" in describing the type of technological innovation dealt with here even though this word tends to change its meaning from one institution or situation to another. In short, what is dealt with here are significant or "radical" innovations which would tend to be the basis for important patent estates of real significance in setting national policy.

In general, the time period referred to in Bright's "proposition" will be defined as the time from the initial idea, when patent applications are generally made, until commercial practice is far enough along so that gross profits in any one year will cover expenses for that year; in other words when annual net income covers annual expenses. (This happens before gross profits will have reached the level to defray previous research, development and other patient money inputs for the *same* product in previous years.)

**Director, Licensing, Monsanto Company, St. Louis, Mo.*

HISTORICAL EXAMPLES

A classic case often cited is that of the Xerox copier. According to Bright[3] the inventor Carlson began his work in 1934, and this innovation did not reach sufficiently broad use to break even financially until 1955-1957. Thus some 20 years passed before the innovation could be termed a success, and even here these 1955 sales were not for office copying but rather for making lithographic plates. If one were to consider Carlson's goal — the office copier — another 5 years was required and a quarter of a century went by.

It is sometimes pointed out that a classic exception to the time usually required for the innovation process is that of atomic weapons development in the United States where the government picked up the innovation after the initial development of theory and carried out multiple approaches to the development on a massive scale. Note, however, that in the follow-on case of nuclear electric power for civilian use commercialization was reached only recently. Nuclear electric power has been over 20 years in going from invention to commercialization.

Brown has made some observations based on original case histories compiled by Jewkes on a number of major inventions in the chemical, mechanical and electrical area over the past 50 years. Of 20 major chemical innovations of the 20th century, less than half show a time interval of less than 10 years between conception and innovation. Table I following combines Brown's data with additional information from Jewkes' case histories. In some cases the year of commercial success is estimated from the general flow of events since the data do not always include precise information on commercial success and profitability.

Parenthetically, national origins of the inventions and innovations show that not all inventions are innovated in the same country where they are invented.

Brown further observes that a majority of 27 major electrical and mechanical innovations of the 20th Century showed a time lag of more than 10 years as shown in Table II which is again a composite of data from the Brown paper and the Jewkes case histories.

A Battelle study provides further data on the duration from initial conception and first realization for each of 9 important developments; these are shown in Table III.[5]

TIME INTERVAL BETWEEN INVENTIONS AND INNOVATIONS

Selected Major Chemical Inventions of the Past 50 Years

Innovation	Date of Invention	Date of Commercial Success	Interval in Years
Bakelite	1909 (U.S.)	1913 (U.S.	4
Cat. Cracking	1925-30 (Fr.)	1941 (U.S.)	11+
Cellophane	1912 (Fr.)	1924 (Fr.)	12
Crease Resist. Fab.	1929 (Gr. Brit.)	1932 (Gr. Brit.)	3
DDT	1939 (Sw.)	1942 (Sw.)	3
Hardening of Liquid Fats	1902 (Ger.)	1909 (Gr. Brit.)	7
Insulin	1920 (Can.)	1925 (Can. & U.S.)	5
KODACHROME Film	1923 (U.S.)	1935 (U.S.)	12
Methyl Methacrylate Polymers	1930 (Can.)	1936 (U.S.)	6
Neoprene	1925 (U.S.)	1932 (U.S.)	7
Nylon	1928 (U.S.)	1939 (U.S.)	11
ORLON Fiber	1942 (U.S.)	1948 (U.S.)	6
Penicillin	1928 (Gr. Brit.)	1944 (U.S.)	16
Polyethylene	1933 (Gr. Brit.)	1944 (U.S.)	11
Silicones	1904 (Gr. Brit.)	1943 (U.S.)	39
Streptomycin	1939 (U.S.)	1944 (U.S.)	5
Synthetic Detergents	1913 (Ger. & Sw.)	1930 (Ger. & Sw.)	17
Polyester Fiber	1941 (Gr. Brit.)	1953 (U.S.)	12
TE Lead	1921 (U.S.)	1930 (U.S.)	9
TEFLON Plastic	1939 (U.S.)	1945 (U.S.)	6

Table I

For some of the innovations in the Battelle study the time from conception to realization was very short, as in the case of the videotape recorder which was developed within six years from its initial conception. Other innovations covered a much longer time span. From the small sample of innovations studied, according to Battelle, there is no evidence that the period from conception to realization is becoming shorter. The three innovations completed since 1960 averaged 19 years, and one of them (the heart pacemaker) involved the longest time span. The average for the nine innovations studied was 18 years.

An explanation of the striking difference between the longest duration and the shortest gives some insight into the variety of circumstances surrounding innovations. The development of the heart pacemaker, which was 32 years in the process, faced a number of inhibiting influences, including social taboos, active opposition within the medical profession and outside it, and the diversion of medical resources away from this project during World War II. Yet its more serious obstacle was probably the absence of necessary technology, as in electronics and materials. On the other hand the videotape recorder required only existing technology and so proceeded from first conception to first realization in six years.

With all of the data so far shown, it is of little wonder that with the time lags and high interest rates that innovation costs today are indeed formidable. For example, in the field of agricultural chemicals the estimated cost per pesticide for discovery and development is $7.6 million which includes the cost of compounds which were not commercialized. Schwartzman has placed the average development cost per single new pharmaceutical entity at $24.4 million in 1973.[5]

Agricultural Chemicals

A recent industry study in the field of agricultural chemicals in the U.S. has shown that compounds registered by the Environmental Protection Agency (EPA) in 1974-75 had been discovered an average of 97 months (or eight years) previously.[6] Within this 97-month period the average time from first submission of the experimental registration petition to the granting of full registration took 42 months. Further time is required for the development of data on efficacy, environmental impact, residue and metabolism, toxicology and process. Preparing and conducting so-called two-year feeding studies takes from $2^1/_2$ to 3 years.

Private communication from Monsanto Company showed elapsed times from year of first conception to year of commercial success on seven projects varied from 6 to 22 years and averaged 12 years as shown in Table IV.

REASONS FOR LENGTH OF TIME REQUIRED

When one examines in detail what must occur in the innovation process, it becomes obvious why the proposition of at least a 10-year span for the innovation process is valid and how infrequently exceptions occur in the case of relatively "radical" innovations. Bright[3] has proposed

TIME INTERVAL BETWEEN INVENTIONS AND INNOVATIONS

Selected Major Electrical and Mechanical Innovations of the Past 50 Years

Innovation	Date of Invention	Date of Commercial Success	Interval in years
Air Cush. Vehicle	1955 (Gr. Brit.)	1968 (Gr. Brit.)	13
Ball-point Pen	1938 (Hung.)	1944 (Argentina)	6
Cont. Casting of Steel	1948 (Ger.)	1954 (Ger.)	6
Cont. Hot Strip Rolling	1920 (U.S.)	1926 (U.S.)	6
Cotton Picker	1910 (U.S.)	1942 (U.S.)	32
Diesel-Electric	1903 (Gr. Brit.)	1934 (U.S.)	31
Elect. Digital Computers	1942 (U.S.)	1951 (U.S.)	9
Float Glass	1952 (Gr. Brit.)	1960 (Gr. Brit.)	8
Fluorescent Light	1923 (Ger.)	1938 (U.S.)	15
Gyro-compass	1865 (Fr.)	1911 (Ger.)	46
Helicopter	1909 (USSR)	1932 (U.S.)	23
Hydro. Transmission	1930 (U.S.)	1937 (U.S.)	7
Jet Engine	1929 (Gr. Brit.)	1943 (Gr. Brit.)	14
L.P. Record	1945 (U.S.)	1948 (U.S.)	3
Osygen Steel Making	1939 (Switz.)	1952 (Austria)	13
PHOTON Photo Sett. Machine	1946 (Fr.)	1962 (U.S.)	16
Plastic Tape Rec.	1929 (Austria)	1940 (Ger.)	11
Power Steering	1925 (U.S.)	1931 (U.S.)	6
Radar	1922 (U.S.)	1935 (France)	13
Radio - Heterodyne System	1905 (U.S.)	1918 (U.S.)	13
Safety Razor	1895 (U.S.)	1906 (U.S.)	11
Self-Wind. Watch	1922 (Gr. Brit.)	1930 (Swiss)	8
Shell Moulding	1941 (Ger.)	1947 (U.S.)	6
Stainless Steel	1911 (Ger.)	1920 (Gr. Brit.)	9
Television	1919 (U.S.)	1941 (U.S.)	22
Xerography	1934 (U.S.)	1955 (U.S.)	21
Zipper	1891 (U.S.)	1918 (U.S.)	27

Table II

DURATION OF THE INNOVATIVE PROCESS FOR NINE INNOVATIONS

Innovation	Date of Invention	Date of Commercial Success	Duration, Years
Heart Pacemaker	1928	1960	32
Hybrid Corn	1908	1933	25
Hybrid Small Grains	1937	1956	19
Green Revolution Wheat	1950	1966	16
Electrophotography	1937	1959	22
Organophosphorus Insecticides	1934	1947	13
Oral Contraceptive	1951	1960	9
Magnetic Ferrites	1933	1955	22
Video Tape Recorder	1950	1956	6
Average Duration			18.2 years

Table III

DURATION OF THE INNOVATIVE PROCESS
FOR SEVEN INNOVATIONS

Project	Date of Invention	Date of Commercial Success	Duration, Years
Early grass specific herbicides	1950	1960	10
ACRILAN acrylic fiber	1943	1962	19
ASTROTURF stadium surfaces	1963	1973	10
ASTROTURF door mats	1965	1971	6
SKYDROL hydraulic fluid	1948	1955	7
CEREX non-woven fabric	1963	1973	10
Polyelectrolytes	1943	1965	22

Table IV

that the innovation process can be broken down into about eight stages, and this alone would indicate that eight years would be a very conservative estimate. In many instances one step alone might involve several years of effort.

Bright's various stages are outlined as follows:

Stage 1 — Scientific suggestion, discovery and observation, or recognition of need

Most innovations seem to begin with the latter, but there are notable exceptions such as atomic power, the laser, and penicillin.

Stage 2 — Development of theory or design concept

While early theories or designs usually are imperfect, their definition leads to a focus of effort along certain lines. In many technical innovations, new scientific theory is not necessary or may be late in coming. Then a combination of known science and/or technology — a design concept — is the goal of this stage.

Stage 3 — Laboratory verification of theory or design concept

This is the laboratory experiment which simply confirms the validity and the principle suggested in Stage 2.

Stage 4 — Laboratory demonstration of application

Here the concept is first embodied in a breadboard model of the device, a sample material or a laboratory model of the process as it would be used (hopefully) by society. In other words the concept is demonstrated in application form.

Stage 5 — Field trial or full scale trial

This stage is defined as the achievement of *technical* success under normal operating conditions. In the specific case of such things as agricultural chemicals and pharmaceuticals, field trials and clinical testing also require time-consuming government and environment impact clearances.

Stage 6 — Commercial introduction

The line between stages 5 and 6 is sometimes far from clear and may be shifted simply by intent. The implication meant for Stage 6 is that the innovation has been purchased in the belief that it is now reliable enough for the marketplace. Here again in such products as agricultural chemicals and pharmaceuticals additional governmental registration requirements must be documented and met.

Stage 7 — Widespread adoption (Initial Commercial Success)

There are several ways that the success of this stage can be defined, but the one used here is the "annual break-even point" or the time when annual gross profits at least cover annual expenses *for that year*. Included in this stage is one of the most treacherous of all steps for manufactured products: production startup.

Stage 8 — Proliferation

The innovation is used in a number of devices, and its principle is adopted for other purposes (new uses, new materials, etc.) The innovation spreads in two ways: (a) the original device is applied to a number of new uses (on more than an experimental scale) and (b) the technical or scientific principle is applied to other machines, processes or materials (e.g. for "a", to consider how radar spread from military uses to commercial planes, ships, air traffic control, police cars and private boats; for "b" consider how microwave technology of radar was applied to commercial heating, cooking to microwave communications systems).

IMPORTANCE OF THE PATENT SYSTEM TO THE INNOVATION PROCESS

Although it is not the purpose here to deal broadly with an overall defense of the patent system, there is one philosophical aspect of particular importance to the thrust of this paper. Patents tend to serve two different but closely related functions:

1) Incentive for the inventor.
2) Protection for the innovator (or entrepreneur-developer).

As Jewkes puts it, for the individual inventor or small producer struggling to market a new idea, the patent right is crucially important. It is the only resource he possesses, and fragile and precarious as his rights may be, without them he would have nothing with which to establish a claim to a financial reward for his work. The sale of his idea directly or the raising of capital for exploiting the idea would be hopeless without a patent.[2] Just as this paper has shown that the length of time required in the innovation process is not diminishing, it is equally apparent that the day of the individual inventor is far from over. Of the 47 major innovations listed in Tables I and II, 32 or 68% involved independent inventors.

Other systems have been proposed for rewarding the inventor, such as certificates of invention granted to inventors in socialist countries where all initiatives are controlled by the state and where a competitive system of private enterprise does not exist. A certificate of invention, however, provides no exclusive licensing rights and therefore is simply not an institution designed to encourage an entrepreneur or developer to assume the huge risk involved during a 6-to-25-year period of innovation.

Competitive System

The patent system is most robustly defended and embodies the most extensive monopoly rights in those countries which most tenaciously adhere to the competitive system of private enterprise. The U.S., for example, is one of the few countries where the patentee has the right to withhold his patent from use entirely without bringing into action public provisions of compulsory licensing except in certain limited areas of public interest. Even in areas of public interest, however, recent U.S. government policies have demonstrated an interest in permitting exclusive licenses of government-held patents for the specific purpose of permitting private industry to justify high-risk investment in the innovation or development process.

At the same time, although it is important to the understanding of the system to distinguish incentive for the inventor from protection for the innovator, it is equally important to realize that these two functions are intimately related. Otherwise there would be no way for the inventor to exploit his idea, either by raising the capital to do it himself or by licensing his rights on an exclusive basis to some developer willing to take the risk. The point should not be lost that practically all of the examples cited in this paper were innovated (or commercially developed) in countries with competitive systems of private enterprise and strong patent protection. The tables show that most of these commercial reductions to practice occurred in the United States where patent law, although undergoing gradual evolution over the years, has remained essentially unchanged in principle for 200 years. British patent practice dates back to the Statute of Monopolies in 1624 which established for "the first and true inventor" rewards in the form of grants of conditional and limited monopolies.

CONCLUSIONS

In spite of the popular notion that all technological progress is accelerating, the evidence is that not much has changed or seems likely to change, in the 10-25-year time span assumption of the proposition posed here. Even in the exceptional case of atomic weapons in which the U.S. government picked up the innovation after Stage 2 (development of theory) and carried out multiple approaches to development through Stages 4, 5 and 6 on a massive scale, this could be the exception that proves the rule; for nuclear power for civilian use, Stage 7 was reached only recently. Nuclear power has been over 20 years in going from Stage 2 to Stage 7, despite the head start given by the development of atomic weapons.

The manager or entrepreneur dealing with a radical or patentable invention presented to him in Stage 4 (laboratory application) must think of supporting the project for roughly a decade to reach significant profits.

At the same time it must certainly be acknowledged that a precise determination of what the patent term should be is not an easy question. It is worth noting that most of the developed free world either has or will have a term of 20 years from filing. This is true of the European patent and is likely to be true in the U.S. In Japan the patent term is 15 years from publication for purposes of opposition, but no longer than 20 years from filing. All of these terms have been selected after long periods of successful experience with the patent system.

Professor Ward S. Bowman, Jr. in his book dealing with a legal and economic appraisal of the patent and antitrust laws, provides a useful discussion of the subject on pages 48-51.[7] His conclusion is that, while a term of 17 years from issue is arbitrary, it is best judged by determining whether, on the whole, the protection of patentable information is over-rewarded or under-rewarded. His conclusion is that the latter is far more likely than the former.

Reducing or eliminating the term for patent protection will destroy an important incentive toward improving the level of technological development in any country, developed or developing. Critics of the patent system, in their concentration on the rights of the inventor, seem to overlook the incentives the system provides to the innovation (or development) process in a competitive free-market economy. Although reward to the inventor is important, particularly for reasons of fairness and ethics, it is risk protection for the innovator which fuels the engine of national economic development. In addition, it is the inventor's ability to offer *exclusive* rights under his patents that is a major factor in establishing their value.

NOTES

1. Brown, Alfred E. "Invention and Innovation — Who and How", *Chemtech*, December 1973, page 709.
2. Jewkes, Sawers and Stillerman "The Sources of Invention", Second Edition, W. W. Norton 1969.
3. Bright, James R. "Some Management Lessons from Technological Innovation Research", *Les Nouvelles*, November 1969, Volume 4, No. 5.
4. Globe, Levy and Schwartz, "Key Factors and Events in the Innovation Process," *Research Management*, July 1973.
5. David Schwartzman, "The Expected Return from Pharmaceutical Research," Washington, American Enterprise Institute for Public Policy Research, 1975, p. 28.
6. Environmental Protection Agency Report #EPA-540/9-75-018, February 1975, "Evaluation of the Possible Impact of Pesticide Legislation on Research and Development Activities of Pesticide Manufacturers", Aldred E. Wechsler, Joan E. Harrison and John Neumeyer (Consultant).
7. Ward S. Bowman, Jr. "Patent and Antitrust Law, a Legal and Economic Appraisal", University of Chicago Press, 1973.