

1 The Investment Decision Phases in Modern Invention and Innovation

It should not be concluded that there is a necessary correlation between the magnitude of research and development expenditures and the importance of inventions produced. Many major advances in science and technology have been brought into the world at relatively little expense. Some, like Dr. Alexander Fleming's discovery of penicillin, originate from an unsolicited accident combined with the rare ability to recognize new possibilities in an event that has happened many times before. Others result from research and development efforts that are modest relative to the importance of the outcome. Lee De Forest's audion, for example—probably the most important invention in electronics—was conceived during the inventor's part-time experiments concurrent with more mundane engineering duties. The General Electric Company spent only \$116,856 in its successful efforts to devise a method for producing ductile tungsten, and only \$195,000 in developing the gas-filled lamp—trifling sums, considering the importance of the results.¹ The German prototype aircraft which made the world's first jet-propelled flight in 1939 required only \$100,000 in developmental expenditures.²

On the other hand, the enormous outlays made to create many of our very complex new products and processes frequently contribute little in the way of basically new technology. In much of the work done to design new automobiles, airplanes, guided missiles, electronic data-processing equipment, communications systems, and other complex products, the primary problem is one of integrating already invented components and subcomponents into a system that operates reliably as a whole. This is accomplished through the costly and time-consuming process of trial and error, and during this process wholly new inventions arise more by accident than by requirement or intent.

In this apparent incongruity between the cost of research and development and the importance of technical advances obtained thereby lies the key to understanding the investment decisions made in modern technological invention and innovation. It has already been mentioned that R & D activity can be classified on a spectrum of specificity, and that the more fundamental types of research comprise only a small percentage of R & D activity. More important is the fact that, in the creation of complex

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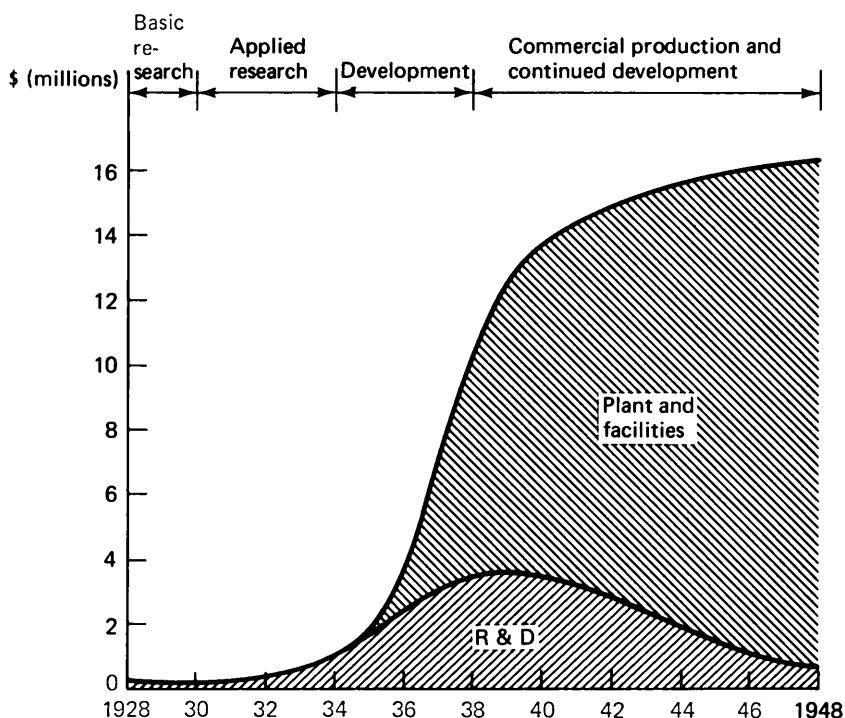


Figure 1.1

DuPont's annual investment in nylon, 1928–1948. The data that permitted the plotting of this investment curve came from a number of sources, including *U. S. v. Imperial Chemical Industries, Ltd.*, 105 F. Supp. 215, 222 (1952); Mitchell Wilson, *American Science and Invention*, (New York: Simon and Schuster, 1954), p. 388; and Floyd L. Vaughan, *The United States Patent System*, (Norman: University of Oklahoma Press, 1956), p. 10. The curves have been somewhat smoothed in construction of the chart.

new products and processes, the various phases of research and development fall into a logical and highly ordered sequence.

This sequence is best illustrated by an actual case example concerning the development of nylon. It can be expressed in terms of a curve showing DuPont's investment in the new synthetic fiber as a function of time, figure 1.1. As the figure shows, the creation of nylon began in 1928 with the basic research of Wallace H. Carothers. When Carothers' small group made the initial discovery in 1930 of synthetic fiber possibilities, less than \$50,000 had been spent. By 1934, after research expenditures of \$1 million, the nylon superpolymer was synthesized. Following these fundamental

breakthroughs, the tempo of research increased as basic properties of the new synthetic were analyzed and as alternative approaches were contemplated. When the invention went to DuPont's development sections, an additional \$44 million was spent to devise mass production processes, test pilot process models, incorporate manufacturing improvements, and improve the fiber's quality. During these latter phases many more people became involved in the project, expensive equipment had to be fabricated, and improvements had to be tested and revised in a costly process of trial and error. Long before the final improvements were conceived, outlays for manufacturing facilities which dwarfed the expenditures on R & D commenced.

From this investment curve analysis, it is readily seen that DuPont's investment in nylon was not one sweeping decision but a series of related decisions, each requiring a higher rate of investment. But as the rate of investment increased, the amount of technical information for use in the decisions also increased. The question, "Can a synthetic fiber be created?" was answered at a relatively low expenditure level. Answers to "Does the fiber have commercial quality possibilities?" and to "Can the fiber be mass-produced economically?" were secured at higher rates of investment, but before really major outlays for plant and equipment began. With each successive step the technical uncertainties became less fundamental.

The nylon story represents a rather pure case of a complex technological development. In it a basic technical breakthrough was followed fairly quickly by the recognition of possible economic applications, and then by rapidly increasing investment in product and process development and in manufacturing facilities. Nevertheless, it illustrates cogently a principle that has widespread application in the innovation of new products and processes: the concept of confining phases of high technological uncertainty to low-spending-level phases of research, undertaking costly specific development projects only when these basic uncertainties have been sufficiently reduced.

The question then arises, How is it possible to reduce these technical uncertainties sufficiently while maintaining a low spending level? This question is often stated in the more practical terms of, How can we spend so little on basic research?

To answer these questions is to clarify the economic distinction between invention and innovation. The allocation of tangible resources—money, engineers, and materials—is much less important in the securing of

invention than it is in the perfection and integration of available inventions into commercially feasible products and processes. In the creation of basic inventions, intangibles such as time, the “flash of genius,” and the overall advance of science are equally important. Physical resources allocated to the support of basic research, or simply to bringing scientists and engineers into contact with the unsolved problems of technology, provide the institutional setting where these intangibles operate. But when, where, and how a basic invention will occur is difficult if not impossible to predict.

In contrast, once the necessary inventions are available, the development of new products or processes to the innovation stage depends largely upon the allocation of human and material resources in order to solve through costly trial and error the detailed problems of technical advance.³ Solving these problems is frequently difficult and takes time. But, as an executive of one leading industrial laboratory stated, the capable scientist or engineer knows that with a hardheaded attack they can in fact be solved. The allocation of resources to solve these problems is one of the principal elements of innovation, and the processes of specific development required for innovation comprise the bulk of U.S. research and development expenditures.

The distinction in an economic sense between invention and the development processes underlying innovation is best summarized in the difference between the two words “predictability” and “describability.” Basic invention is truly unpredictable: even the most competent scientist cannot predict when or how it will come, let alone what the solution will resemble. On the other hand, he or she knows in appraising the detailed problems of development that an answer will be obtained and can only not describe what the answer will be.

It must be recognized, however, that invention, like many other things, is a matter of degree. There are highly dramatic breakthroughs and relatively unexciting ones; inventions may be highly complex and sophisticated, or the essence of simplicity. Nevertheless, the concept of confining activities of relatively high technical uncertainty to low-spending-level phases of research and development is applicable equally well to very complex or very plain innovations. It is simply sound management of resources to eliminate as many unpredictables and undescribables as one can before committing substantial investments in prototypes, testing, and manufacturing facilities. As a result the nylon investment curve shown

in figure 1.1 is strikingly typical of all cases where new products and new processes are developed for quantity production.⁴

Notes

1. Arthur A. Bright, Jr., *The Electric Lamp Industry* (New York: Macmillan, 1949), pp. 195 and 323.

2. Robert Schlaifer, Big Business and Small Business: A Case Study, *Harvard Business Review* (July 1950): 107.

3. The reader is again warned of the distinction between the economist's definition of invention and that used in patent law. Although the solutions to these detailed technical problems are not considered inventions in the economic sense, they typically possess the inventive qualities required for patentability.

4. See, for example, the diagrams presented by Lawrence H. Hafstad, vice-president of research for General Motors, in "Research or Invention," *Proceedings of the 10th National Conference on the Administration of Research* (University Park, Pa.: Pennsylvania State University Press, 1957), p. 123. This concept is partially rejected in "crash" developments and in the military "weapon system" approach to weapons development. In these cases the pressure of competition forces the developer to sacrifice certainty for lead time. Even in the "weapon system" approach, however, resolution of initial component problems necessitates an investment curve similar to the one present in figure 1.1. See J. S. Butz, Jr., Rivalry Intense in Soviet Weapon Design, *Aviation Week* (November 24, 1958): 91.