Industrial research is inefficient and chaotic, but it works (*)

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ABSTRACT.—Industrial research is inefficient and chaotic, but it works.

Effective R&D programs are essential if the U.S. is to regain the position as the world's technological leader. The key to successful R&D programs is an understanding of how the R&D process fits into and affects the overall industrial picture.

RESUMEN.—La investigación industrial es ineficiente y caótica, pero funciona.

Los programas de Investigación y Desarrollo (I+D) son fundamentales en los Estados Unidos para recuperar su posición de líder de la tecnología mundial. La clave del éxito en los programas de I+D es el comprender perfectamente cómo afecta y cómo se acopla el proceso I+D en el campo industrial.

1. RELATIONSHIPS BETWEEN R&D AND SUBSEQUENT INNOVATION

Essential consensus has been reached on the need for increased innovation in our industries, but there is still some mystery about the relationship between R&D and subsequent innovation. I find this a fascinating and complex topic which I will attempt to explore with you.

The dilemma we face has been clearly stated by Dr. Robert Holland, president of the Committee for Economic Development, in testimony before the U.S. House of Representatives:

«I do not know or anybody who does not think R&D is good, but in a world of scarce resources, we face the problem of deciding how much to do. We have to weigh who benefits and how much; how it is to be divided up; and what other activities to compare it with in making these decisions» (1).

To determine how much to do and how to divide it up requires some understanding of the link between R&D and innovation and what parameters define successful R&D, or understanding what types of R&D provide new or improved goods and services. The first step is to define innovation and then to discover how it is supported by science and technology. The second step is to determine how to structure our R&D efforts to cause innovation to occur.

One of the most cogent definitions of innovation that I have seen is embodied in a report produced by Battelle Memorial Research Institute for the National Science Foundation entitled «Science, Technology, and Innovation» (2). It states, Innovation is a term that describes certain activities by which our society improves its productivity, standard of living, and economic status. Innovation should be distinguished from scientific discovery, although relevant discoveries may be incorporated into the innovation.

«Innovation also should be differentiated from invention, although an invention frequently provides the initial concept leading to the innovation. Innovation is not merely a marginal improvement to an existing product or process. Rather it is a complex series of activities, beginning at first conception, when the original idea is conceived, proceeding through a succession of interwoven steps of research, development, engineering design, market analysis, management decision making, etc.; and ending at first realization when an industrially successful product, which may actually successful product, which may actually be a thing, technique, or process, is accepted in the marketplace.» For research managers, the problem is to design research programs so that they foster the entire innovation process.

An overall argument for the role of R&D in innovation has been made by many, particularly R&D managers who suffer a credibility problem because they seem to be self-serving. However, their arguments are significantly enhanced by economists who have worked out econometric models which relate outputs to various inputs including R&D (1). The results of these studies can be summarized in the following observations:

— In general, productivity in an industry or firm is directly and significantly related to the amount spent previously on R&D efforts.

— There is a significant lag between the time when R&D expenditures occur and the time when productivity increases. The lag is longest for basic research, moderate for applied research, and short for development. For inventions leading to major innovations the lag is normally a decade or more in length.

— R&D provides improvements in the quality of goods and services and can reduce costs for equivalent quality products over time.

If the amount of applied research is maintained constant, a direct correlation exists between the amount of basic research carried out and the rate of productivity increases.

If expenditures for R&D are constant, the rate of productivity growth is directly related to the extent that R&D is consistent and long term.

R&D is an **effective anti-inflation measure.** For example, gasoline would have cost \$1.45 in 1955 for 100 ton-miles if the Burton refining process had still been in use. Instead, because of a number of cracking innovations, it was actually 26¢. Construction of large-scale ammonia plants in the 1960s reduced costs by 20%. This resulted in reduced agricultural costs and eventually lower food prices. These observations and their subsequent conclusions formed the basis for passing the Economic Recovery Tax Act of 1981 which incorporates special incentives for increased R&D spending.

**2. INFLUENCE OF FUNDAMENTAL RESEARCH ON INDUSTRIAL PRODUCTIVITY**

Well-studied examples of specific industries and their overall success as a function of R&D spending are few. However, several case studies have been made; i.e., the chemical, semiconductor, and microelectronics industries. The Chemical industry is a particularly attractive case since it has a long history and has been studied over a relatively long time span (3).

From 1860 to 1970, this industry enjoyed rapid and continuous growth consistent with its high level of technological innovation. Real growth averaged 7.5% annually over this 110-year time span. However, changing ideas of management in the 1950s and 1960s caused this industry in general to shift to increased emphasis on short-term profit and a reallocation of R&D investment toward a larger percentage or applied research and engineering.

Although there are a number of other important factors, it is tempting to conclude that the present problem in the chemical industry is due, at least in part, to drastically reduced R&D expenditures in the 1970s. At the very least, these data indicate the pitfalls encountered in assuming that a mature industry does not require the R&D expenditures necessary to continue diversification and new product entries in new business lines.

This idea was expressed succinctly by Charles Kettering, longtime director of research at General Motors, who said, "The headlamp of industry is its change-making department. No business of any kind can keep on indefinitely doing what it is doing now. It must change or go under" (4).

In addition to the overall R&D funding level, there is a question of research mix, long term vs short term, and the direction set by industrial management; i.e., identification of R&D areas from market research, high-value commercial products vs low-cost consumer products, etc. First, we will take a look at research mix.

To some, the progress from fundamental research to commercial product or process is seen as a lockstep progression from basic science activities to applied research, to development, to product or process. Unfortunately, this orderly progression is almost never realized, and major innovations can come directly from basic research or from targeted, or applied, research programs.

Two well-known examples come to mind. Wilhelm Roentgen discovered x rays while studying a very basic problem in the physics of rays emitted from a Crookes tube. This discovery was converted almost immediately into a diagnostic tool which provided a real leap forward for surgery and disease management.

A contrast is provided by the work of Pasteur who was assigned by the French government to the practical tasks of how to keep wine from turning to vinegar and how to save sheep dying from anthrax. In the search for solutions to these practical problems, Parteurs discovered bacteria and founded the field of modern bacteriology.

To evaluate the respective roles of basic and applied research, several retrospective studies have been carried out. In an evaluation of the scientific basis for the support of biomedical science, Conroe and Dripps identified significant clinical advances and determined the sequence of research which led to their development (5). To understand their conclusions, one must clearly perceive the definitions they use to provide measurement guidelines.

Another extensive study, in totally different areas of technology, is represented by the National Science Foundation TRACES project. This program focused on several major technological innovations and attempted to trace the history of all of the science and technology that contributed to the advancements which led to the innovation (2). We will look at two examples.

The first is the development of hybrid grains and the subsequent "Green Revolution." The concept was first enunciated in 1908 and was followed by the development of hybrid corn in 1933 and ultimately offshoots to improvements in varietal wheat and small grains. The entire innovation process was driven by knowledge acquired in genetic research followed by long development programs.

A totally different example is the development of the video tape recorder. In this example a wide variety of scientific discoveries, theoretical studies, and electronic development work converge to provide the background for the concept...
of the rotatinghead video recorder. The prior work was done for a variety of reasons but was essential to the overall success of the commercial development.

The conception of the recorder itself was a consequence of the perceived need for a technique to record video signals for subsequent broadcasting. Once the technical problems were identified, the progress was quite rapid. The first commercial unit was demonstrated by Ampex in 1956 only six years after its conception in 1950.

3. MARKET RESEARCH

Other examples of the failure of market research in innovative areas are pocket calculators and computers. One firm conducted a study in the early 1970s and found no potential for pocket calculators. Initial market forecasts after World War II suggested that there would be an ultimate demand for 10 large mainframe computers worldwide.

These examples do not negate the need and utility of good market research. They simply point out that normal market strategies for improved existing products are not necessarily applicable to innovative products. This is an area that could profit from additional study.

The other interesting component of the video recorder story is the subsequent movement of the market to consumer products supplied by non-U.S. firms. The initial Ampex recorder cost $60,000 in 1956. Subsequent R&D reduced tape usage by a half by 1962. A similar unit was offered by Sony in the same year at about the same cost but with slightly less tape usage.

U.S. firms concentrated on the industrial and professional markets and other nations concentrated on the consumer market. By 1980, Philips marketed a unit for $520 which used less than a hundredth of the needed in the original Ampex equipment.

The National Science Foundation study included other thrusts in addition to the TRACES information (2). Decisive events were identified and the question of innovation management was posed. In identifying decisive events and the factors which were important in those events, correlations could be made between innovation and research atmospheres. The factors which were ranked most important included recognition of technical opportunity, recognition of the need, internal R&D management, management venture division, funding availability, technical entrepreneurs, and in-house colleagues.

4. THE STAGES OF INNOVATION

The stages of innovation had, on average, a different mix of R&D efforts prior to the conception of the innovation: the major contributing factors were nonmission-oriented research which very little development input. During the innovative period, mission-oriented research was dominant with an almost equal importance of development. These relative positions were reversed during the post-innovative period with development making the largest contribution, followed by mission-oriented research with little contribution from nonmission-oriented activities.

The major conclusions drawn about innovative management were that the process cannot be completely controlled or programmed. The synergistic interactions of nonmission-oriented research, mission-oriented research, and development were determined more by the individual personnel than they were by tightly designed programs. The inventive and creative activities that are required do not lend themselves well to detailed planning.

However, certain conditions could be identified which help the innovative process to materialize. The major conditions were continuity of funding, an interdisciplinary atmosphere, and freedom to act upon ideas that fall outside the programmed research.

As a final overall comment, it is worthwhile to look at where R&D is today. Fortunately, the outlook is promising for the long term. Data indicate that total R&D expenditures are actually rising again as a percentage of gross national product. A reasonable mix of dollars among the various types of research seems to be in place and no major dislocations are evident although development expenditures are rising more rapidly than research (fig. 1).

It also is significant to note that during past recessions research programs in the industrial sector have been the first activities to be reduced. The present recession appears so far to be an exception. Certainly other industrial expenditures have been reduced significantly, but overall R&D spending appears to be holding through the end of 1982 although there has been a recent softening of this position. This is a very positive sign which would suggest that long-term prospects for increased U.S. industrial vitality are good if the current recession does not last significantly beyond 1982.

5. CONCLUSION

I would like to leave you with the following thoughts about research productivity. Pasteur once said, "To him who devotes his life to science, nothing can give more happiness than increasing the number of discoveries. But his cup of joy is full when the results of his studies immediately find practical application. There are not two sciences. There is only one science and the application of science, and these two activities are linked as the fruit is to the tree".

My personal belief is that productive industrial research is somewhat like democracy. It is inefficient, sometimes chaotic, and generally directed by amateur managers. However, it works—and until we have a better solution, we should nurture and support it.

6. REFERENCES

Curso sobre materias primas para cerámica y vidrio

Temas sobre fisioquímica, tecnología, geología, economía.

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La publicación recoge la labor realizada en un curso intensivo sobre el tema, celebrado en Madrid en 1986. Todos los trabajos que la componen están realizados por personas que poseen probada experiencia en sus respectivas especialidades lo que hace que, en muchos casos, sirvan al sector desde puestos de alta responsabilidad.

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