Understanding R&D Productivity

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Preface

The phrase "R&D productivity" embodies a large part of our conception of modern industry. "Productivity" - getting more output with less input - is the older notion, an icon of the industrial revolution that has inspired both the industrialist who sought it and the social critic who despised it. "R&D" - research and development - is of more recent import, capturing the modern association of science and technology with industry.

As one might expect from so heavily laden a phrase, our understanding of R&D productivity is a complex and incomplete one. More correctly, perhaps, we have many different conceptions of what R&D productivity means and many different formulas for its achievement; each of these visions adds an element to our overall understanding. There is no single unified theory of R&D productivity, no agreed-upon method of analyzing it, no unique approach to increasing it. But in the intelligent juxtaposition of diverse perspectives there can arise a coherent portrait of the state of our understanding of this important and far-reaching topic.

And therein lies the purpose of this volume: to present just such a set of perspectives, to assemble the views of some of the foremost students and practitioners of research and development.

Each of the chapters that follow was first presented at a seminar series organized by the Center for Science and Technology Policy at New York University during the spring semester of 1981. The participants include well-known academic and government scholars from several disciplines, along with top business executives responsible for the actual planning and conduct of industrial R&D.

Now, one can understand the topic "R&D productivity" in two ways: as concerned with the productivity of R&D itself -

as, for example, in an industrial laboratory - or as concerned with the import of R&D for overall industrial or economic productiveness. It was the first of these that we charged our speakers with exploring. But we knew from the start that the two sub-topics are ultimately inseparable; and you will see that our authors have ranged widely in both cases.

Here's a preview.

In the first chapter Herbert Fusfeld provides an introduction to the issues of R&D productivity. He suggests a way of viewing the problem and sets forth the questions that need to be answered.

The next chapters tackle the vexing problems of measurement. Charles Falk and Roberta Balstad Miller offer their thoughts on the conceptual and practical problems of data collection and interpretation.

Economics provides another view. Richard Nelson shows us how an economist - albeit a somewhat heterodox one - looks at R&D productivity and its relation to economic growth. And Richard Levin takes a close-up look at R&D productivity in the semiconductor industry, suggesting that, although a slackening in that industry's phenomenal rate of technical change is inevitable, the slowdown may not be as near as many people think.

Both William Abernathy and D. Bruce Merrifield examine the relationship of R&D productivity to corporate planning and management strategy. Abernathy elaborates on his controversial thesis that management style and outlook must bear much of the blame for a relative decline in the innovativeness of American industry. By contrast, Merrifield assigns inflation a greater role in the current problems of industry; but he echoes Abernathy's view that R&D and corporate planning should be more fully integrated, and he provides us with a positive vision of the future.

Another set of concerns take shape from the perspective of those concerned with the management of R&D laboratories. Lowell Steele takes us through the many considerations that enter into the evaluation of R&D projects in a commercial setting. And Arthur Anderson deals with the often-overlooked problem of improving an R&D system that is already functioning well.

In the penultimate chapter, Arthur Damask brings a physicist's ingenuity and thoroughness to the question of R&D productivity. The first half of his paper catalogues some of the empirical laws of productivity proposed through the centuries, while the second half presents a bold attempt to apply the mathematics of information theory to the problems of R&D management.

Finally, Alfred Nissan surveys all that came before, and concludes that the problems of R&D productivity discussed in these essays remain unsolved and manifestly complex. In a brief afterword, Herbert Fusfeld offers a more upbeat counterpoint to Nissan's conclusion, suggesting some reasonable courses that might be pursued.

The editors would like to thank the authors of the chapters in this volume for taking the time from their busy schedules to participate in the seminar series and to prepare their remarks for publication. We would also like to thank Barbara Muench for helping to organize the seminars, Shawn Roberts for typing the manuscript in a truly professional manner, and Carlos Santiago for rendering elegantly many of the diagrams. The task of preparing the seminar materials for publication was supported by a grant from Alfred P. Sloan Foundation - a grant without which this volume would not have been possible and for which we are extremely grateful.

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Introduction: An Initial Approach to Understanding and Improving R&D Productivity

Herbert I. Fusfeld

PHILOSOPHICAL BASIS

I would like to introduce this subject on a personal note. During 25 years in industrial research, I have probably visited between 150 and 200 laboratories. After several hours at a location, following brief discussions with senior management and research staff, talking with more junior researchers about their programs, observing the nature of the research facilities and the level of activity, I would come away with a general impression as to whether that laboratory was a "productive" unit.

This was a highly subjective feeling since there were few, if any, quantitative data about performance. Nothing was measured or counted. On what basis could I arrive, rightly or wrongly, at a judgment about the "productivity" of the laboratory? There were obviously some clues in the statement of objectives, the sense of priorities, the sense of morale among those carrying out the research, the relationships within the laboratory and, in the case of industrial laboratories, between the laboratory and other parts of the corporation.

None of these is a direct measure of output. I probably assumed certain correlations, particularly for industrial research. First, good communication within the corporation plus a sense of priorities implies that technical progress in research would very likely be exploited by the corporation. Second, good morale within the laboratory implies a sense of security that normally relates to acceptance of the individuals, the laboratory, and their programs.

In short, I was not looking at the laboratory as an isolated unit, but as an integral part of a larger system. The functioning of the laboratory can only be judged by the values and objectives of the system in which it exists and by which it is strongly conditioned. I believe this statement should hold equally for industry, government and the university. There are obviously arguments to be advanced about judging technical progress in an absolute sense. I believe this is a more sophisticated refinement of the general theme that research exists within a structure, although that structure can be private or public, corporate or academic.

Let me pursue this approach one further step. Anyone who has had the responsibility as director of a research laboratory is aware of the many management decisions involved. It is not simply a matter of hiring good researchers, however we judge that; arranging for good housekeeping; and watching for results. There are options as to organizational structure; allocation of resources by programs; allocation of resources among professionals, technicians, and equipment; decisions as to starting or stopping programs; and, particularly, forms of communication between the laboratory and the rest of the system. The point is that any research director believes that he can improve the effectiveness or "productivity" of the laboratory, and the preceding list of options shows some of the tools available to do so.

This brings us back to the problem of R&D productivity. When people believe that the performance of an organization or a system can be improved, one would expect that performance can be defined and hence measured. We are all aware that changes in structure, in priorities, and in resource allocation occur constantly in laboratories throughout government, industry and the university. Words such as improved "effectiveness" and "productivity" are invoked to support such changes. Yet definitions, consensus, and measurements are curiously missing.

Admittedly there is a value judgment, a subjective aspect, in results from research and development that seems to defy easy quantitative formulas for R&D productivity. So be it. The answers will not be easy and they may not be precisely quantitative in an arithmetical sense. Nevertheless, if we can sense that one laboratory is more "productive" than another, if we believe we can take actions to improve the "productivity" of a given laboratory, then we should be able to discuss, analyze and describe the basis for these judgments. Such descriptions should be a first step in identifying criteria for R&D productivity. This would permit evaluation, if not measurement. An understanding of these criteria might then suggest quantities that are measurable and relate to criteria that define R&D productivity.

The remainder of this chapter will suggest a conceptual approach that may provide a few initial steps to this difficult, critical, yet common obstacle to deriving optimum benefits from the truly massive dedication of resources in this country and internationally to science and technology.

STATEMENT OF THE PROBLEM

Considering the United States alone, about $69 billion will be spent on R&D activities in 1981, of which $34 billion will come from the private sector and almost all of the remainder from the federal government.* The ultimate output from this effort will appear to the world outside the R&D community in the form of new products, new processes, new services, and an increase in the reservoir of basic science and engineering. Can we increase the results flowing from this very considerable effort? Can we obtain the same results with fewer dollars?

This broad spectrum of total national technical effort is simply too complex to evaluate as a single system, or to improve in a single approach. The other extreme of considering a single laboratory unit, while it is a necessary first step, would not provide adequate insight about the relationships within the technical community.

I therefore propose to take as a first major objective consideration of the productivity of those R&D activities concerned with the civilian sector. While in the United States this is primarily the $34 billion of industrial research, it is also intended to include those efforts within government and university laboratories whose results could normally be expected to benefit society through traditional economic mechanisms.

In the preceding section, I commented that we judge the work of a laboratory in terms of its role in a larger system. Hence, for our purposes, that larger system is the civilian sector. The principal technical activities and responsibilities for the generation, conversion and integration of science and technology into our economic lives lies with the industrial research structure. Keeping this in mind, the relevant activities of government and university that affect the civilian sector can be considered primarily in terms of their support for, and interaction with, industrial research.

What then will we be examining with this picture in mind? The line of reasoning I would suggest follows this pattern:

1. The overall objective is to derive the optimum benefits for the civilian sector from the ongoing investments in R&D.

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*National Science Foundation, <u>Science Indicators</u> - <u>1980</u> (Washington, D.C., NSB-81-1).

2. The principal instrument for developing these benefits is the industrial research structure.
3. The system we will be examining can be considered in several broad functional categories of industrial research activity:

   a. Internal operations of industrial research organizations.
   b. Linkages between the industrial research structure and overall industry operations that determine the conversion and use of technology as products and services.
   c. Linkages between the industrial research structure and the external world of science and technology, consisting of university and government R&D activities as well as the additions to the technical reservoir coming from industrial advances throughout the world.

4. Special note should be taken of the processes by which government and university research activities intended for the civilian sector are initiated and linked to the system of economic use, since these can critically affect both the available technical reservoir and the stimulation of socially desired industrial activities.

If one were to describe this system with a diagram, it would not be a simple flow in a straight line from technical reservoir to industrial research to manufacture and use. My picture of the system we are considering is more like that of a large number of individual technical organizations floating in a sea of technology. This sea rests within an economic and social structure that determines the direction and magnitude of the technological flow, establishing constraints and pressures. There are infinite interactions and boundary conditions.

From this complex structure of our society, we can extract the activities most likely to generate and convert science and technology for the benefit of that society, and we can identify most of the critical factors that affect this process. Any system we define will be incomplete. Nevertheless, if we can understand and improve the system we define, we can expand it steadily to approach real-life conditions.

SUGGESTED CONCEPTS FOR CONSIDERATION

Since our emphasis is on the productivity of R&D intended for the civilian sector, a first approach to the necessary value judgments should be based upon the benefits perceived by the non-specialist in that sector. To be specific, we could focus on the judgments of the taxpayer, but that would imply a quantitative evaluation that is premature for this stage of study.

Suppose we could consider all relevant technical activities - industry, government and university - as being conducted within a "black box." How would the typical resident of the civilian sector view the "box?"

What goes into the "box" is relatively clear - money and people. But what comes out depends on what we are expecting, and the time scale can be critical. In simple terms, the civilian sector can observe, count, and partially evaluate new products, new processes and new services emerging from the "black box." The products and services are visible to the general public. Processes are less visible, since they form part of the corporate operations in manufacturing or services; but they are identifiable and can be evaluated in terms of lower costs, manufacturing productivity, and so on.

A fourth category of output is the increased reservoir of basic science and engineering. While this is not yet a tangible benefit for the civilian sector, it is a form of asset, a potential technical wealth, and must be included in order to achieve reasonable balance between inputs and outputs even in a descriptive sense. In this area, some kinds of judgments by a scientific peer group will clearly have to be developed and accepted by the nonspecialist.

Putting aside for the moment these additions to the technical reservoir, the general public sees products, processes, and services. It does not see as a current benefit such quantities as patents, articles, reference citations, and the like. These quantities remain in the black box. The possible use of such secondary or proxy quantities may provide clues to the health of our overall technical enterprise, but it requires specialists to interpret such secondary measures and to correlate them with the more tangible outputs.

As I have chosen to define the system, certain features stand out. For example, we can identify several areas for study which affect "productivity." A direct attempt to seek improvement might lead to definitions or evaluations of output from any consensus that emerges. The areas for consideration are:

1. Processes and criteria for selecting research programs. Technical results that do not reach society remain inside the black box. Industrial laboratories include economic disciplines to regulate the probable integration of R&D into business operations. Hence, the difficulties of choosing the "right" problems apply most heavily to government sponsored research and, less directly, to university research.

2. Transfer processes among technical sectors. Our concern is with ultimate benefits derived from the overall R&D system. The output of a single industrial laboratory can be based upon, and is usually influenced by, specific government and university research activities plus worldwide technical

advances from all sectors. The mechanisms for transfer via traditional professional activities, organized information systems, and specific cooperative arrangements are important to R&D productivity.

3. Effectiveness of individual laboratory R&D operations. There is constant pressure to allocate given resources for the optimum output. Since each laboratory has unique objectives and values, the most constructive general activity is to develop references for comparison and self-improvement. This calls for consensus as to important factors, and identification of differences between technical sectors and among separate industries.

I have suggested the "black box" concept of R&D as viewed by the average citizen in order to develop some sense of outputs. Many refinements will come to mind as we consider the details. There is the need to set up a separate evaluation for increases in our basic technical reservoir. There is the need to consider the economic impact of specific developments. There is increasing pressure to evaluate contributions to health, safety and the environment. There are real values in prestige that affect foreign policy, and thus our ultimate well-being.

The pragmatic concept of tangible output is then only a simplified first step. Still, it is understandable, and therefore can permit us to progress to more sophisticated levels.

APPROACHES TO THE PROBLEM

First understanding, then optimizing, a complex system calls for many contributions. A number of parallel approaches are clearly possible and desirable. It is only important that all approaches deal with the same system; therefore, I have repeated my own concepts in somewhat elementary detail.

Different approaches can be identified in terms of their content. Several examples to be considered are:

By Function

1. Direct Improvement. This has been discussed in the preceding section. Admittedly, there is a slightly illogical aspect to considering improvements in something not yet well-defined or measurable. But this is precisely what is done regularly in every research organization. Keeping in mind the broader objectives, an orderly analysis of such improvements may provide agreement on the nature of outputs and of value judgments. This is the focus for practitioners of research management.

2. Economic Impacts. Every new product, process, or service has an economic value, and we should eventually be in a position to define and estimate that value. It is different for the institution funding the R&D, for the user, and for society as a whole. This is the primary field of study for economic scholars like E. Mansfield, R.R. Nelson and others.

3. Measurements. Agreement on outputs is one of the ultimate results of a systematic approach to R&D productivity. Still, there is value in preparing a basis for discussion concerning (a) the significance of quantities that we do measure, and (b) the nature of quantities that can be measured. Several types of quantities that can be considered, to be discussed in more detail at the end of this section, include:

1. Identifiable outputs
2. Proxy or secondary indices
3. Characteristics of R&D operations
4. Technological progress functions.

Some relevant data are reported by the Commerce Department and the Science Resources Division of the National Science Foundation. The latter would be the more directly concerned with identified and measurable indices relating to this subject.

By Structure

1. Industrial research within a single corporation. The objectives, expectations and outputs within a given company should serve to provide qualitative definitions of productivity. History of change and efforts at improvement would strengthen definitions.

2. Industrial research within a single industry. Examining the origin and nature of technical change within a particular industry should broaden our view of both inputs and outputs. We would expect a perspective on R&D productivity for an industry to be different from that for a single company. This larger perspective could include such cooperative efforts as trade association research.

3. External R&D related to a single industry. Research within government and university laboratories that is intended to support a particular industrial area should be studied in conjunction with separate studies of that area. The evaluation of outputs would then combine both the technical progress of