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THE STATISTICS OF RESEARCH AND DEVELOPMENT*

Report of the Secretary-General

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I. INTRODUCTION

1. Although research and development (R and D) are old activities, they have become relatively more important since the beginning of the century and especially since World War II. This is indicated by the rapid expansion in the volume of R and D, as well as by the radical changes that have occurred in their organization and management. The latter refers to the transformation of the work from being largely an individual effort to that consisting of a mass approach in terms of extensive laboratories employing numerous scientists and engineers and elaborate facilities.

2. The rapid growth of research and development has resulted recently in the formulation of programmes to measure the various aspects of these activities. Such programmes are designed to quantify both the input and output factors of R and D. On the input side, the measurements deal with the financial and manpower resources devoted to the activities, and considerable progress has already been made along these lines in some countries. In terms of output, the measurements cover such aspects as publications and patents, but the success of the efforts here have been less pronounced. This paper deals largely with the input statistics of R and D, although at the end some attention is devoted to output data and the inherent difficulties accounting for the lack of progress thus far in this area.

II. RELATION OF RESEARCH AND DEVELOPMENT TO SCIENCE AND TECHNOLOGY

3. Research and development are an integral part of science and technology, which are composed of a number of elements that are closely intermeshed, each influencing the other and all contributing to the total picture. Hence, in discussing the statistics of R and D, it is essential to delineate the latter and analyse their relationship to the other aspects of science and technology. Perhaps the proper way to accomplish this task is to begin with a discussion of science and technology as a whole, followed by a more specific description of its various manifestations, although as a result of shortage of space this can only be done in brief terms.

4. In defining science and technology, it is advisable first to treat each separately and later describe the dependence of one upon the other. Science has been designated as a body of knowledge consisting of generalizations in terms of laws or tendencies on the basis of observed natural and social phenomena. This is the result of the application of a scientific method, which covers the making of quantitative or qualitative observations, classifying and summarizing the facts obtained, and subjecting them to an analytical treatment to test prior hypotheses to produce these generalizations. The vast knowledge thus obtained has been classified into substantive areas, including the physical, environmental, biological, and social sciences, each of which consists of a large number of specialized fields. In contrast, technology has been defined as the existing know-how of individuals and society employed in producing the capital and consumer goods and services for satisfying life. Of course, technology also includes the facilities, both plant and equipment, used in achieving these goals, but the emphasis is on the ability to manage the whole complex, namely the planning, operation, and maintenance of all tools and processes involved in the production of goods and services. Technology may also be classified according to its various industrial activities, which are quite numerous to enumerate even in the broadest terms. Obviously, technology is dependent on science for the basic knowledge and applications to maintain and advance its state, and without the results of science it would soon reach a level of existence that is stationary and devoid of progress.

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5. The relationship between science and technology may be further amplified by a consideration of the principal activities included under each term. Whereas technology is actually concerned with the exercise of the know-how in the production of goods and services, the activities of science cover research and development and science education that are responsible for this technological knowledge.

6. Research and development constitute the most creative activities in science and technology. First, they cover basic research that is responsible for scientific discoveries relating to the fundamental laws of nature and society, thus having a direct bearing on the extension of the frontiers of knowledge. The potentialities of basic research are boundless, and any expansion of this work serves to enrich our intellectual life and lay the foundation for technical changes. Second, R and D includes all phases of applied research and development, which provide for a constant flow of innovations and inventions. The latter have a direct and immediate effect on the technology, interms of changing the processes of production and goods and services. This applies to the modification of old and the creation of new techniques and output that tend to enrich the material life of members of society. In other words, R and D is the mainspring of science and technology, being responsible for its dynamism and progress over the years.

7. Science education is equally important as an activity in science and technology. It is difficult to dissociate education in the sciences from total education, but the growing importance of science and technology in recent years has resulted in focusing considerable attention on learning in courses directly concerned with this area. The courses involve the basic sciences, as well as their applications in engineering, medicine, agriculture and so on. Science education generally helps to broaden one's total education, but it is particularly designed to develop specialists who can function in a society dominated by science and technology. One goal of science education is to train persons to teach others in the same fields at various levels of the educational system, as without this effort the supply of scientists, both theoretical and applied, would tend to become exhausted. Another aim is to provide individuals in the basic and applied sciences to do research and development, as well as to carry on the various jobs in our technology. Due to the rapid strides in science and technology, there is

the factor of obsolescence following the term of formal education, which must be counteracted by educational activities in adult years. The programmes in science education involve considerable financial and manpower resources, which have an immediate effect on the economy and contribute to its long-range development and growth.

8. In addition to R and D and science education, there are other activities that need to be mentioned as regards science and technology, namely, the collection of general purpose data, dissemination of scientific and technical information, and testing and standardization. Every one of these has a direct bearing on research and development, from either a conceptual or statistical point of view, and they are often referred to as R and D related activities. This necessitates describing the latter in order to be able later to draw the line between each of them and R and D.

9. In a number of countries, there are extensive programmes involving the collection of general purpose data that extend to numerous fields, which are usually covered by governmental and semi-public agencies. Some of these programmes are associated with applications in the natural sciences, such as surveys of geological and geophysical work, coast and geodetic surveys, exploration activities in connexion with oil and mineral resources, the gathering and arrangement of biological specimens and the like. Other programmes are connected with the social sciences, including the compilation of social and economic data, health statistics, and the like. The collection of these data are fairly well routinized, and they often take the form of repetitive surveys of a most detailed nature. Although some of the results obtained may be used as a basis for specific analytical purposes in scientific research, most of the output is employed in many varied ways by the general public to fulfil either partially scientific or non-scientific objectives. It should be pointed out that considerable financial and manpower resources are devoted to these programmes.

10. With the phenomenal growth of R and D, there has occurred a vast extension during recent years in the activity relating to the dissemination of scientific information. The number of scientific and technical journals has multiplied rapidly, in order to accommodate the seemingly endless flow of articles discussing the results of R and D. To this must be added a substantial increase in other

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publications, including reports, monographs, manuals, and books. It is essential that the members of the scientific community keep abreast of new developments, and meeting this demand has become an important concern of science and technology. This involves not only the task of producing publications, but it also includes the creation and maintenance of efficient science library collections and facilities. The services rendered by the latter comprise such items as translations, documentation, abstracting, and other library activities. Some of this work has been mechanized in order to facilitate the process of retrieval of scientific information. The total effort is not only related to research and development but to science education as well, since its aim is to educate and inform all segments of the population. Considerable financial and manpower resources are devoted to the dissemination of science information, although the volume is barely able to keep up with the growing needs of the scientific establishment.

11. In an age of science and technology, testing and standardization constitute an indispensable activity. Designed to promote accuracy and precision in scientific measurement and analysis, these are basically service functions to aid R and D and the operation of the technology. Often testing and standardization are carried on in government laboratories, in order to give the results the advantages of an official confirmation. Yet, a good deal of the work is performed in the private sector, especially in the business enterprise part of the economy. The persons engaged in the work must have a scientific and technical background, but generally the operations are considered as routine and repetitive in nature. Such activities also involve the allocation of considerable amounts of financial and manpower resources.

III. OVER-ALL CONCEPTUAL AND DEFINITIONAL FRAMEWORK OF RESEARCH AND DEVELOPMENT

A. Conceptual aspects of research and development

12. Although there are certain underlying principles that are used in formulating the conceptual framework of research and development, one is immediately confronted here, as in other areas of statistics, with the qualitative nature of the categorization involved. This necessitates resorting to a descriptive analysis of the classifications which makes it difficult to draw absolute lines of demarcation, so that the outcome is apt to produce grey areas and overlapping. The solution to the problem lies in developing arbitrary division lines, and these are bound to affect the accuracy of the data. R and D are perhaps particularly vulnerable in this respect, due to theoretical differences and varying experiences among persons within the scientific community. Another reason for this situation lies in the relative newness of the R and D statistical programme, as some of the concepts and definitions have not been used long enough to crystallize a common understanding and acceptance.

13. There are three aspects to the problem of categorization in research and development. One involves considering R and D in terms of their scope, which leads to a breakdown by components, namely, basic research, applied research, and development. Another aspect deals with the specific inclusions in and exclusions from R and D, or differentiating them as a whole from other activities, whether or not oriented to science. Lastly, there is the classification of R and D from a substantive point of view, including the various fields covered by both the basic and applied sciences.

1. Components of research and development

14. It is rather difficult to present an integrated definition of research and development, since we are dealing here with two distinct elements as the over-all term implies. Research has been characterized as systematic, intensive study directed toward fuller scientific knowledge of the subject covered. As mentioned before, research may be either basic or applied in nature. By contrast, development deals with the prototypes and processes growing out of the research work.

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15. Each of the above terms needs further elaboration. Basic research may be defined as that directed toward an increase of knowledge in science, with the primary aim of the investigator being a fuller knowledge or understanding of the subject under study rather than a practical application of it. Applied research, on the other hand, is aimed toward a practical application of knowledge, differing from basic research chiefly in terms of the objectives of the investigator. Lastly, development is the systematic use of scientific knowledge directed toward the design and production of useful prototypes, materials, devices, systems, methods, or processes. The words embodied in these definitions may vary among sectoral surveys within a given country, as well as in the surveys of different countries, in order to adapt the language to meet specific situations. Yet, the underlying thoughts of the definitions seem to be everywhere the same, as statistical R and D programmes are undertaken and expanded.

16. In spite of the acceptance of the definitions delineating basic from applied research, there is some controversy on the subject from a theoretical point of view. The distinction between the two terms seems to rely largely on the motivation of the investigator or his sponsoring institution. As a result, some individuals may look on a certain project as basic research, whereas others would regard it as belonging to the realm of applied research, depending on the current conditions under which the work is carried on and the ultimate goals to be achieved. Thus, a distinction is often made between mission-oriented basic research and pure basic research. The former is usually done in government or private industry laboratories, with the basic research being restricted to the mission of the organization and the hope that the work will ultimately benefit its applied research. On the other hand, pure basic research has no such restriction, being performed in accordance with the scientific interests of the investigator, a situation that is most conducive to the free choices prevailing in an academic atmosphere. In fact, the investigators and administrators of research in the government and private industry are sometimes accused of a built-in bias in classifying projects, shifting them to either basic or applied research due to political or related exigencies. Nevertheless, it is true that applied research owes much to the fundamental knowledge emanatirg from basic research, and studies have been made of the time lag between specific findings in the latter and

particular innovations in the former. Also it has been argued in favour of expanding and stockpiling fundamental research, as sooner or later it will be of help to applied research.

17. Likewise, there are practical difficulties in distinguishing between basic and applied research in responding to statistical inquiries. It is quite easy to classify the work when it is carried on in separate laboratories or sections, but the task becomes complicated if the activities are intermingled organizationally. Under such conditions, it is hard to maintain separate records on basic and applied research. It thus becomes necessary to make arbitrary allocations in terms of the budget or manpower involved. This may not be too serious if the selections are in concurrence with the investigator or his supervisor, but often this job is done by the accounting personnel who are limited in their knowledge of the work to allocate the figures properly.

18. The demarcation between applied research and development can be justified on the ground that the former is responsible for the principles underlying the innovation and the latter for the engineering and testing of it. The development activity may range from the construction of a single prototype to a total pilot plant to produce specific new materials, products, devices, processes, etc., or to improve old ones. There is an intimate relationship between applied research and development, and sometimes the development work may require further applied research. As a result, it is often difficult to separate the financial and manpower resources allocated to each component in the statistical survey.

19. It has been argued that, in view of the theoretical and practical difficulties inherent in separating basic research, applied research, and development, it might be advisable to omit any breakdown within the scope of R and D in the statistical inquiry. This would indeed be an easy solution, but it is essential to produce data for each component as a basis for policy- and decision-making in this important area. As experience has shown, basic research is often neglected, and it is necessary to maintain a proper balance between it and applied research and development, as guided by the statistics. Also, figures are needed to aid in the proper allocation of resources for each component. Both basic and applied research are less costly than development, the former requiring relatively larger contingents of manpower but lesser amounts of expensive facilities and equipment, as compared with the latter. Hence, the availability of data by R and D components is an essential part of the statistical programme.

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2. Exclusions and inclusions under research and development

20. In making statistical surveys of research and development, one cannot rely solely on the general definitions of the latter and their components. Many questions arise as to specific exclusions and inclusions with respect to the scope of R and D. Some of these are predictable on the basis of past experience, but new ones are bound to appear in the course of the inquiries over the years. The major exclusions and inclusions that have been recognized must be considered with reference to the total work outside of research and development, including science education and activities related to R and D and the vast operations that fall completely beyond the boundaries of science.

21. Science education and the R-and-D related activities have already been described previously in some detail. It is obvious that science education, although it is creative in fashioning the minds of students and preparing many for scientific and technical work, does not fall within the purview of research and development that are concerned with the extension of scientific knowledge. The same thing applies to general-purpose data collection, dissemination of scientific and technical information, and testing and standardization, which have been characterized basically as routine and repetitive in nature, even though many of the personnel involved are scientists and technicians, as already indicated. It is true that these activities are helpful to R and D, but they do not modify or augment the body of scientific knowledge. Yet, there has been considerable pressure at times from individuals and organizations to cover such activities as integral parts of R and D, due largely to a desire of the proponents to enhance the image of these programmes in the eyes of society. Such a course would enormously exaggerate the volume of R and D, creating a situation that would confuse the public and policy-makers as regards the true import of research and development.

22. On the other hand, there is scientific work connected with the above activities that should be separated from the repetitive operations and included under R and D. This involves the development of theories and principles, systems and techniques, and various other innovations, on the basis of the application of scientific methods, which play an important role in advancing science education and R-and-D-related activities. Thus, a distinction should be made between studies in psychology and work on innovations to enhance the learning process from the actual

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teaching programmes in science and total education. Similar identifications should be emphasized between genuine R and D and the repetitive operational activities in general-purpose data collection, dissemination of scientific and technical information, and testing and standardization. For example, the investigation of new methods of measuring temperature and pressure more accurately in the atmosphere is research, as distinguished from the non-research nature of the recording of daily routine data in the same field. Likewise, the invention of a translation machine is part of R and D, which may be contrasted with the tedious work of translation involved in programmes of disseminating information. Lastly, the development of a new process for testing materials is a research effort, as compared with the later uses of this process in routine testing work. The resources devoted to R and D in science education and the related activities are less extensive than those used in the operational programmes in each area, but they are sufficiently important to be reported separately and included in the total R and D picture.

23. Turning to the numerous activities outside the boundaried of science, the main consideration is to draw a line of demarcation between R and D and the production and distribution of goods and services in the economy. This is not an easy task to perform, and perhaps the best guideline is contained in a statement of the United States National Science Foundation, as follows: "If the primary objective is to make further improvements on the product or process, then the work comes within the definition of research and development. If, on the other hand, the product or process is substantially 'set', and the primary objective is to develop markets or to do preproduction planning, or to get the production process going smoothly, then the work is no longer research and development." However, within the production process, there are certain operations that are often mistaken for R and D, and they should be specifically excluded. The latter cover research on patents and licences, quality control, routine product testing, market research, sales promotion, routine technical services offered to customers, and other technical or non-technical activities incidental to production and distribution.

3. Classification of research and development by fields of science

24. A classification of research and development by fields of science is important, but the progress here has been slow and generally unsatisfactory. This is not the

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fault of the individuals interested in the problem, the situation being due to special circumstances that have made it difficult to conceptualize in this area.

25. The need for a breakdown by fields of science is not confined to R and D, as it also concerns teaching in science education. In fact, the organizational structure of higher education is predicated on specialization by field in both activities, involving schools, divisions, departments, and smaller units. Teaching was probably more of a determining factor in the organization of academic science in the early years, but recently the rapid changes brought about by R and D have produced new alignments in universities and colleges.

26. Changes in the classification by fields reflect the progress made in the substantive aspects of science. As a result of increased specialization, the broad fields of science used in the past are being continuously proliferated, with each new field narrowing in scope but assuming greater profundity in its probing. Furthermore, these new fields often disregard the boundaries of the old ones, acquiring whatever scientific content is needed to advance their respective specializations. At the same time, there has been a trend toward the formulation of large interdisciplinary fields, such as oceanography and weather control and modification, each of which combines various aspects of other fields to meet their goals and programme needs. Indeed, the definitions of the interdisciplinary sciences cut across any systematic breakdowns on the basis of the numerous specializations mentioned above, so that it becomes difficult to keep track of both types of fields.

27. A breakdown by field is also needed as a basis for policy decisions in the planning and administration of science. The demand emanates from university officials, scientists in professional societies and kindred groups, and government administrators of science programmes in various agencies. In an effort to advance the interests of science, it is important to have a fairly detailed and homogeneous classification by field, so that the requirements of each specialty may be properly evaluated and equitable allocations made in terms of available financial and manpower resources. This necessitates the presentation of data by science fields to accord with the situation in the scientific community.

28. The presentation by scientific fields in statistical surveys is generally in terms of relatively broad categories. Thus, the broadest classes used cover the life sciences (biological, medical, and agricultural), psychological sciences,

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physical sciences (physical sciences proper, engineering sciences, and mathematics), social sciences, and other sciences. This classification may be carried to a further level of detail. For example, the physical sciences proper are broken down to show astronomy, chemistry, atmospheric sciences, oceanography, solid earth sciences, elementary partial physics, nuclear structure physics, atomic, molecular and solid state physics, other physics, and other physical sciences proper. Likewise, the engineering sciences are subdivided to include aeronautical, astronautical, chemical, civil, electrical, mechanical, metallurgy and materials, and other engineering. However, there is a strong demand for further levels of detail, in order to satisfy the increasing trend in specialization. A classification involving several hundred breakdowns was once tried out by the United States National Science Foundation in a projection survey of R and D in the Federal Government sector, but the results showed limited accuracy and meaning in the final analysis. On the whole, it has been the experience of the Foundation, under present circumstances, to avoid detailed categories, in order to preserve the quality of the statistics obtained in the surveys.

29. A major difficulty with any detailed classification by fields of science is the element of overlapping in the categories used, especially as regards closely related areas of knowledge that are often not easily amenable to differentiation, or with respect to the new interdisciplinary sciences that bring together numerous specializations from already established disciplines. Furthermore, an attempt to set up arbitrary lines of demarcation often meets with controversial reactions from scientists and administrators, who are apt to balk at anything imposed from the outside that affects the substantive content of the work or interferes with existing organizational lines. Of course, the underlying factor in this problem is the highly dynamic state in the sciences, but this is not expected to level off in the years ahead. At any rate, the crucial element in the situation is the acceptability of the classification, but perhaps that may be solved in time by discussion and education.

30. Accordingly, the eventual solution to the problem may be the formulation of a standard classification of fields of science, similar to those covering industries or causes of death. This should be based on technical discussions among scientists, science administrators, and statisticians working in the area.

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It should include several levels of detail to meet existing needs, being revised at intervals to take account of new scientific developments. The classification should aim to minimize the overlapping of fields, as well as facilitate the application of uniform practices in the allocation of activities. Care should be taken to co-ordinate this classification with one involving a breakdown of scientific and technical personnel by fields of professional specialization, so that it could be used generally for all activities in higher education. It should have both national and international applications. As regards the latter, considerable work has already been done by UNESCO, but additional efforts need to be made to perfect the system and gain its acceptance throughout the world.

31. Another solution to the problem consists of making special investigations to cover particular scientific fields, in addition to the over-all periodic surveys that embrace all R and D and science education activities. This type of survey has the advantage of great flexibility, as its scope in terms of scientific fields and detail of information to be obtained can be determined at will by those promoting the inquiry. Several surveys of this kind have been made in the United States with great success, and they have served a useful purpose in providing the needed data for planning and administering programmes. It should be remembered, however, that the results of these surveys are often not apt to be additive due to overlapping, and besides the expense and effort involved are considerable, so that too many of them cannot be undertaken to present an extensive picture of the scientific activities.

B. The sectoral approach to research and development

32. Having described the conceptual nature of research and development, the next step is to take up the institutional framework involving these activities. This covers the sectoral approach, including the structural and other characteristics of each sector in the economy playing a role in the financing and performance of R and D.

33. There are several reasons for using the sectoral approach in dealing with research and development. One reason is embodied in the practical considerations of data collection, since each sector necessitates a different type of inquiry in

terms of the contents of the questionnaire. Another reason is that, as regards expenditures, the most reliable way of building up national aggregates in a country is by means of sectoral statistics, which reflect the intersectoral flow of funds in the financing and performance of R and D. Lastly, an important reason for the sectoral breakdown is with relation to the analysis of the data, requiring comparisons of R and D with other economic figures, many of which are presented by sectors.

34. The sectoral breakdown in research and development is not unlike that used generally in statistical and economic analysis. First, there is the government sector, as distinguished from the private sectors of the economy. The latter comprise the business enterprise sector, the higher education sector, and the so-called non-profit sector covering many types of institutions. To be sure, the higher education sector also consists of non-profit institutions, either private or public, but its importance in R and D and the independent role it plays necessitates treating it as a distinct sector.

35. In dealing with the government sector, one must distinguish between the central government and the provincial and local governments, and each may be regarded as a subsector of the total entity. The central government is by far the most important in the economy, as it plays a dominant role in the formulation of national policy in research and development, as well as being usually the main source of funds for the latter. The contributions made to R and D by the provincial and local governments are quite limited, although there has been some expansion here in recent years. The motivating factor in government R and D is the performance of work that is related to functions that are traditionally and historically public in nature.

36. The business enterprise sector is made up of firms and organizations that are privately owned and operated, whose motivating factor is to earn a profit on the basis of their activities and investment in connexion with research and development. Most of these firms are integrated companies, which are engaged in R and D as one of the various functions they perform in the production of goods and services to the general public or as a special service to the government. A number of firms, often referred to as commercial laboratories, devote themselves exclusively to R and D, contracting their services to private firms and the government. Closely

related to this segment are the individual inventors, working either part- or full-time, who after patenting their inventions will offer them for sale to any willing buyer in the market. Finally, there are some co-operative research organizations, promoted by trade associations and similar groups, which engaged in R and D for the benefit of their membership, many of whom might be firms that are unwilling or cannot afford to undertake such activities on their own. It should be pointed out that the entire business enterprise community is usually the leading performer of R and D among the sectors in the economy.

37. Some questions arise as to the line of demarcation between the government and business enterprise sectors. For instance, the government sector will sometimes support research and development in certain projects associated with industrial activities in which the initial outlays are very large, so that the business enterprise sector cannot justify the expense in terms of profit returns until a certain level of progress has been achieved. This applies to the peaceful uses of atomic energy, hypersonic aircraft, and the like. Since the support in such fields are intimately connected with long-range national interests, it is perhaps justified to include the expenditures under the government sector. Furthermore, due to the fact that private industry may be generally unable to afford R and D work, some countries have extensive programmes whereby the government will subsidize its performance in the business enterprise sector, and perhaps in this instance the expenditures should be allocated to the latter rather than the public sector. However, there is no question with respect to partially or fully state-owned or -managed industrial undertakings, where the R and D activities are an integral part of the latter, so that they should be definitely included in the business enterprise sector. This is significant from the standpoint of international comparisons on a sectoral basis, as will be pointed out later in this paper.

38. The higher education sector has a number of unique characteristics with respect to research and development. Within its limits, research and science education are intimately related in practice, in a manner whereby one enriches the other. As regards R and D, the emphasis is on basic research, with some applied research but relatively little development work. The support of R and D in this sector emanates mostly from outside sources, especially the government sector, the latter

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playing a dominant role in both public and private institutions. The organization of R and D within the higher education sector varies considerably, especially from one country to another. Some of the research work is performed within the regular departments, but most of it tends to concentrate in special institutes attached to universities, higher schools of technology, and other schools of higher learning. Sometimes, there are questions raised as to whether certain research institutes actually belong to the higher education sector. This is true of the so-called Federal Contract Research Centers in the United States, which are totally financed, equipped, and managed by the government sector. Such organizations, one might say, are merely nominally connected with the colleges and universities involved, as there exists very little contact between them and the academic departments of the school.

39. In describing the miscellaneous non-profit sector, one is confronted with a number of homogeneous segments, each with its own characteristics with respect to research and development. One of the segments deals with private foundations, and some of the larger ones are involved in R and D. Financed mainly by endowments, they support R and D within their own confines, universities, or in other parts of the economy. Since their financial resources are relatively limited, they tend to concentrate in certain fields of research, such as medical, social sciences, and other fields they feel should receive particular attention. Another segment consists of the "not for profit" research institutes, which are almost entirely performers of R and D. Some of them may have been originally part of a university or endowed as a separate entity, but sooner or later they are financed by contracts from the government and private industry engaging in many aspects of R and D in the natural, biological and social sciences. These contracts often yield a profit to the institutes, but since the latter are not stock companies the surplus is dug back into the organization to be used for various purposes, such as raising salaries to attract better personnel, improving the plant facilities and equipment, and undertaking research projects of their own selection. A third segment consists of independent health agencies and hospitals, supported by donations from wide sources, which finance or perform research on certain disease or special health projects. A fourth segment are the academies of science, professional scientific societies, and similar groups, which are supported by

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grants and contracts from other sectors, dues and individual contributions, and other items of income, the R and D they perform depending on the professional interests of the members of the respective organizations. There are other segements, like museums, arboreta, and botanical and zoological gardens, receiving funds from various sources and engaging in research to cover their individual interests. It should be pointed out that the above enumeration fits largely the situation in the United States, but other countries rely on one or more of these segments for their R and D. Yet, all told, the miscellaneous non-profit institutions play a minor role in the total R and D in any country.

C. Measurements of research and development activities

40. On the input side, we have two measurements of activities in research and development, namely, those based on financial and manpower data. Each type of measurement has some advantages and disadvantages, as will be pointed out later in the discussion. However, it is not a question of using exclusively one or the other, although this may be necessary temporarily in some countries. Rather, the best results are obtained by using both measurements, as they complement each other to produce the best possible presentation of R and D.

1. Financial measurement of research and development

41. There are two aspects to the financial measurement of research and development, one involving current operating expenditures and the other capital expenditures. The former is by far more extensive than the latter, but the combination of the two is needed to obtain a full picture of R and D financing. In treating each separately, however, the main difficulty lies in distinguishing one from the other, which requires the formulation of specific instructions to guide the respondents in the statistical surveys.

42. Current operating expenditures cover a variety of items, which may be grouped within several broad categories, such as salaries and wages, equipment and materials, and miscellaneous and overhead expenses. The salaries and wages paid to the R and D personnel, to which one must add fringe benefits of all kinds, constitute a major element in the total expenditures. In dealing with equipment,

one should not overlook the various scientific instruments employed in R and D, outside of the important capital installations, as they have been playing a constantly growing role in mechanizing the work. The materials involve a large number of individual articles and supplies, some used on an over-all basis and others needed to carry on specific R and D operations. The miscellaneous and overhead expenses cover rent, maintenance of buildings and facilities, utilities, travel and transportation, insurance, administrative expenses, etc. In case R and D is integrated with other operations in a large organization, a proportionate share of the overhead costs should be allocated to the former activity. For the total statistical analysis, it is sufficient to obtain a single figure for all the current operating expenditures, but for special purposes it may be worth-while to collect separate data for some groupings, including salaries and wages, instruments, and the like.

43. In measuring current operating expenditures for research and development, a distinction should be made between the sources of funds and the performance of the work. Some organizations are involved only in one or the other, but many of them play a dual role, financing their own performance of R and D and that carried on by outside agencies. Hence, respondents should be asked to separate "intramural" and "extramural expenditures", the former covering all funds used for performance within an organization, whatever may be the sources of financing, and the latter including all funds spent on the performance outside the organization. Furthermore, the sources of financing should be allocated by performing sectors, so that it will be possible to develop a picture of the inter-sectoral flow of funds. The extent of intramural and extramural expenditures varies from one sector to another, and they will be described in greater detail in the statistical programmes of the individual sectors, as well as in connexion with the summary data representing the national picture.

44. In general, capital expenditures include buildings and major installations used in research and development. As regards buildings, there are new ones, additions to old structures, and extensive renovations and alterations to improve the existing plant. The major items of equipment and apparatus are sometimes built in on a fixed basis, but often they are movable if necessary. On the other hand, minor improvements to existing buildings, as well as small equipment,

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scientific and general instruments, and various tools are normally excluded. The boundary line between major and minor items differs among organizations, on the basis of accounting practices, but the variations are not apt to be sufficiently significant to affect the data. It is advisable to have the respondent make a separation as between building and equipment costs. At times, R and D are carried on jointly with other operations in the same facilities, in which case a proportion of the total cost must be allocated to the former activity, using some equitable procedure in making the computation.

45. An important problem arises in reporting capital expenditure costs in research and development. Ideally, one should compute the part for replacement of existing facilities, or the depreciation, to which must be added the net increase made during the year. Unfortunately, this procedure is not followed in the government, nor is it generally accepted in the non-profit sectors of the economy. Another difficulty inherent in this process is the variation in the life-span of fixed assets for depreciation purposes. Accordingly, in order to put all sectors on a comparable basis, it is prudent to exclude all depreciation, whether real or imputed, and determine the actual gross capital expenditures for the year, irrespective of methods of financing, the length of the period of write-off, and whether the expenditure is for new capital assets or their replacement.

46. As a measure of R and D activity, the current operating and capital expenditures have the advantage of covering the full range of investment, so that the data reflect all the ramifications in this important area. Consequently, they serve a useful purpose for making many public and private policy decisions in allocating R and D funds, as well as studying the current impact and long-time effects of the latter on the stabilization and growth of the economy. However, any financial data are subject to inflationary influences, so that an effort must be made to determine the extent of this element, if one is to obtain a picture of the trend in terms of constant monetary units.

2. <u>Manpower measurement of research and development</u>

47. The statistics of manpower engaged in research and development may be obtained from two kinds of surveys, one covering scientific and technical personnel involved in all activities and the other being an expenditure investigation of

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R and D in which the data on manpower constitute one of the inquiries. It should be pointed out that any country interested in science and technology should conduct both types of studies. Comprehensive surveys of scientific and technical personnel have a breakdown by functional areas, with the R and D manpower as a distinct entity, which makes it possible to study the latter in relation to total figures. This is important as regards an analysis of R and D personnel from the standpoint of demand and supply and related factors. It is even possible to conduct a study that will yield both comprehensive manpower data and information on R and D expenditures. On the other hand, if surveys of R and D financing are carried out separately, it is essential to cover R and D manpower, since the respective figures are interrelated and their mutual analysis throws additional light on the subject. The present paper will confine itself to manpower data, which are obtained as an integral part of a survey covering statistics of expenditures in R and D.

48. Manpower employed in research and development should be divided into three principal categories, namely, professional scientists and engineers, technicians, and other supporting personnel. Professional scientists and engineers are those who have received a diploma in higher education or have an equivalent status due to other training and experience. Technicians are those with technical knowledge obtained through formal education in special schools above the secondary level or as a result of schooling in private industry and the armed forces, including such occupational groups as draughtsmen, laboratory assistants, electronic technicians, etc. The other supporting personnel cover secretaries, skilled craftsmen, unskilled workers, and other persons directly engaged in R and D activity. The scientists and engineers constitute the core of the R and D personnel and, if one desires, they may be classified by scientific disciplines. The manpower data should also include as a separate category individuals engaged in the management and administration of R and D. Finally, it is essential to point out that the manpower figures should exclude indirect labour of whatever kind, even though the services covered by the latter are part of the expenditure data in the survey.

49. Most of the employees engaged in research and development are on a full-time basis, but a substantial number divide their time between these and other activities, which makes it difficult to get an accurate total figure for R and D

manpower. This is true in private industry, where certain employees engaged in R and D also devote some time to production, testing and standardization, sales and distribution, general administration, etc. This participation in several activities is particularly the custom in higher education, with numerous faculty members being occupied with both research and teaching or administration. One solution is to request separate figures for full-time and part-time employees in R and D, but this procedure is devoid of a precise total figure. Another solution is to allocate the part-time R and D personnel, on the basis of having spent 50 per cent or more of their time in this activity. Perhaps the best solution is to use the "full-time equivalent" concept, whereby the part-time work is converted to full-time in accordance with the proportion of the total hours or actual man-hours devoted to R and D. This method yields a relatively accurate figure of the total input of man-years into R and D.

50. It has been argued that expenditure statistics may be derived from manpower data in research and development, which precludes the need for expenditure surveys. Thus, the R and D manpower figures can be multiplied by the average cost per scientist and engineer, either estimated or based on actual records obtained from respondents. This procedure was followed prior to the time any studies were undertaken, and in the early years it was even employed in survey techniques. The latter was done because respondents often objected to disclosing detailed expenditure data, or it was felt that this represented a simplified approach to obtaining financial figures. However, the above method was later replaced by surveys designed to obtain expenditure statistics in a direct manner.

51. It should be emphasized that the use of the manpower measurement exclusively underestimates to a consderable extent the full import of the research and development activity, since the data represent merely the direct labour covered, thus excluding indirect labour expense and the cost of numerous other inputs. On the other hand, manpower figures do not contain the inflationary element present in the expenditure statistics. Used jointly, therefore, the two sets of data present a comprehensive approach in the measurement of R and D, in terms of policy formulation and economic analysis.

IV. STATISTICAL SURVEYS IN RESEARCH AND DEVELOPMENT

52. The next part of the discussion covers a description of the statistical programme in research and development, as it concerns each sector and the economy as a whole. This will involve showing how the over-all concepts and definitions are applied to the sectoral surveys and the national statistics, as well as developing additional concepts and definitions peculiar to each set of data. Lastly, there is the need of outlining the limitations inherent in the sectoral and national figures.

A. Sectoral surveys of research and development

1. Government surveys of research and development

53. Most of the discussion here will deal with the statistical programme describing the efforts of the central government in research and development, which are both extensive in scope and far-reaching in the results obtained. At the end, however, some attention will be given to R and D data covering the limited work of provincial and local governments, the surveys of which are still in the formative stages of development.

54. In formulating the statistical programme of research and development in a country, one is apt to start with the central government survey to set the pace for inquiries in the other sectors in the economy. This survey should be carried out annually and on a 100 per cent basis, using the mail questionnaire along with individual contacts to take care of problems arising in the course of the inquiry.

55. One problem that may arise in surveys of research and development in the central government is connected with the length of the budgetary process. The proposed budget requires legislative approval, after which the appropriated funds are allocated to the agencies involved in R and D. It takes some time, however, for the money to be obligated to the performers, as well as transforming the funds into actual expenditures. In the United States, for example, the data in the annual survey of R and D are obtained for a period of three years, representing the budgetary cycle. The figures for the earliest year represent actual expenditures, but those for the middle and current year are estimates of expenditures based on obligations in various degrees. This factor affects the accuracy of the more recent

figures, which are subject to modifications in the course of changes to actual expenditures. It should be remembered that this problem is inherent in the financing of both current operations and capital facilities of R and D.

56. In most countries, the research and development activities within the national government are decentralized, involving a number of ministries and departments and independent agencies. In canvassing each of the latter, moreover, it is necessary to obtain a breakdown of the data by lower organizational levels. This will aid in analysing the figures, especially from the standpoint of policy formulation and allocation of resources to cover the various programmes in the Government.

57. It is difficult to obtain statistics of research and development in the central government to reflect the various functional activities, because the latter are not apt to correspond with the organizational lines in the government structure. The principal R and D functional activities are national defence, space exploration, atomic energy, health, agriculture, natural resources, and transportation, with many others that are too numerous to mention. Not only do these functional activities in R and D overlap from one agency to another, but some organizations have individual projects that serve more than one function. Moreover, several R and D functions involve the element of state secrecy, which greatly aggravates the situation. Yet, some effort can be made to develop estimates on the basis of collected data for certain functions, even though they will be subject to considerable margins of error. In particular, it is essential to delineate between military and civil R and D, especially in the large countries, a subject that has aroused great interest throughout the world.

58. In conducting the statistical survey in the national government, it is necessary to exercise special care in making it conform to the various definitions inherent in research and development. Since the Government is greatly involved in the operational activities covering general-purpose data collection, dissemination of scientific information, and testing and standardization, one must make certain that these are excluded from R and D as reported by individual agencies, except for the limited work in each case that genuinely falls within that scope. On the other hand, the agencies should include any R and D in the

vast government procurement programmes, which are often overlooked in the reporting process. Sometimes, difficulties arise in delineating basic from applied research and development in the government inquiries, as in connexion with the R and D programmes in new areas, such as space exploration, weather control and modification, and oceanography. The same difficulty is apt to occur in such areas as the medical and engineering sciences, in which applied research and development are dominant factors in the situation. Lastly, a relatively clean breakdown by fields of science is important in the R and D surveys of the central government, and efforts need to be made in all cases to produce a common understanding among respondents in the allocation of projects.

59. Of special significance in the research and development surveys of the central government is the distinction between intramural and extramural financing. The intramural activities include the government-owned and operated laboratories and installations engaged in the performance of R and D, as well as the work for planning and administration of contractual and grant programmes. The extramural activities are carried on by the business enterprise, higher education and miscellaneous non-profit sectors, operating on the basis of provisions governing the contracts and grants awarded by the Government to the individual performers in each sector. Accordingly, the inquiry should break down the funds in terms of allocations to each of the four categories of performance.

60. Recently, there has arisen a demand, especially in the large countries, to classify the research and development funds of the national government by geographical divisions within the nation. This demand stems from the realization that R and D play an important role in regional development, so that it is necessary to have an equitable distribution of the funds. It has often been argued that R and D financing has a tendency to concentrate in certain geographical areas, where the facilities for their performance have already reached a high level. Naturally, there is pressure stemming from the less favoured areas, and since one is dealing with government funds the situation is bound to have political overtones. The geographical data may be obtained as part of the general survey, or as a result of a special inquiry at less frequent intervals.

61. Some central governments finance research and development abroad, which should be considered separately in the statistical surveys. This includes funds given to organizations and individuals in foreign lands performing R and D for the Government of a country, as well as its payments to international organizations. On the other hand, it does not cover funds to a country's own agencies and private organizations working outside, nor payments to foreigners employed within its borders. Special care should be exercised in the statistics relating to capital expenditures, including only funds for items purchased abroad but excluding those acquired at home and transported outside for installation. The figures on foreign financing in a given country should be broken down by individual countries to which the payments are forwarded.

62. Thus far, the discussion has dealt with the financial measurements of research and development, but some consideration should be given to parallel manpower data to be obtained in the same surveys of the central government. Of course, the current operating funds of the latter are often devoted largely to extramural activities, leaving only a small share to be covered by both financial and manpower figures related to intramural work. Usually, the R and D manpower data are obtained as part of over-all and separate surveys conducted by the national government, but it would be of great analytical value to cover R and D funds and manpower simultaneously in a single survey. Thus, one could compute various averages, such as the per capita salary paid to scientists and engineers, the average total expenditure per professional worker, etc., all of which would contribute to an understanding of R and D in the national government.

63. The picture is somewhat different in the case of research and development surveys covering state or provincial and local governments. For one thing, the scope of R and D activities to be covered here is more limited as compared with the central government. Thus, one is not concerned with national defence, space exploration, and atomic energy, but with such programmes as health, housing and urban problems, safety, agriculture, rural problems, transportation, etc., and even in the case of the latter the R and D activities are apt to be limited in range. By contrast, the difficulties of data collection are multiplied considerably, in view of the large number of governmental units involved. Perhaps the provincial governments could be surveyed with full coverage, but sampling would

certainly have to be used for municipal and local governments, especially in the large countries. Most of the problems discussed in connexion with surveys of the central government will be confronted in the local governments, but perhaps they will be substantially intensified in relation to the latter area. It is advised that any country-wide survey of R and D in lower levels of governmental activity be undertaken with great caution, and it should be preceded perhaps by pilot projects covering a limited number of governmental units. It is essential to point out that, while the R and D activities are important to individual provincial and local areas, if added up, their total volume would not materially change the picture for the entire government sector or the economy as a whole.

2. Surveys of research and development in the business enterprise sector

64. The statistical survey of research and development in the business enterprise sector is quite complicated in nature. Not only does the inquiry involve some variables that are difficult to measure, but it may be conducted under circumstances that do not ensure full co-operation from respondents. R and D is considered by many companies an activity of strategic importance in the competitive field, and their is bound to be restraint in divulging information to the agency conducting the survey. This reluctance can be overcome gradually by enlisting the aid of individual trade associations, as well as of national associations of industrial and commercial concerns. It is also essential that the survey be conducted by the same agency in the Government responsible for the periodical collection of all statistics covering the manufacturing and non-manufacturing industries, so that it will be possible later to compute significant ratios of R and D and other economic variables on a comparable basis.

65. In view of its importance, the survey of research and development in the business enterprise sector of a country should be conducted annually, or at least biennially. Generally the mail questionnaire method can be employed, but this will need to be supplemented with field visits, especially in the early years of investigation. The inquiry should have a wide coverage, including all large- and medium-sized firms and a substantial sample of small concerns. The data for the latter will thus have to be blown up to a 100 per cent basis, in accordance with established statistical practices using other variables as weighting factors.

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66. One of the most important aspects of the survey in the business enterprise sector is the distribution of research and development resources by industrial activity. However, one cannot use here the establishment approach in industrial classification, since most companies are multi-unit in nature, and R and D is carried on in separate laboratories for the benefit of the entire concern. Hence, the reporting unit in R and D inquiries is the company, which is classified in a single industry on the basis of its major productive activity, even though some of its product lines may extend into other industries.

67. With the company as the reporting unit in R and D statistics, it is advisable to present the latter in terms of broad industry groupings, in order to minimize the heterogeneity of the figures. For example, the industrial classification used in the United States is as follows:

Food and kindred products . . . .
Textiles and apparel . . . .
Lumber, wood products, and furniture . . . .
Paper and allied products . . . .
Chemicals and allied products . . . .
    Industrial chemicals . . . .
    Drugs and medicines . . . .
    Other chemicals . . . .
Petroleum refining and extraction . . . .
Rubber products . . . .
Stone, clay, and glass products . . . .
Primary metals . . . .
    Primary ferrous products . . . .
    Non-ferrous and other metal products . . . .
Fabricated metal products . . . .
Machinery . . . .
Electrical equipment and communication . . . .
    Communication equipment and electronic components . . . .
    Other electrical equipment . . . .
Motor vehicles and other transportation equipment . . . .
Aircraft and missiles . . . .
Professional and scientific instruments . . . .
    Scientific and mechanical measuring instruments . . . . .
    Optical, surgical, photographic and other instruments . .
Other manufacturing industries . . . .
Non-manufacturing industries . . . .

Thus, the data are presented in terms of a two-digit breakdown in the United States Standard Industrial Classification. However, greater detail is shown in several areas where the R and D operations are quite important, and only summary figures appear for the remaining manufacturing and non-manufacturing industries.

68. The size of company is another essential factor in the analysis of research and development statistics in the business enterprise sector. By far the greatest volume of R and D work here is performed by the largest concerns, with the medium and small firms playing only minor roles in this activity. It is customary to measure size of company in terms of its total employment engaged in all operations, on the basis of the count during the middle pay period of a representative month in the survey year. Several size classes may be constituted, such as concerns with 5,000 or more, 1,000 to 4,999, and less than 1,000 employees.

69. Mention has already been made of some of the special problems in the business enterprise sector with respect to the concepts and definitions of research and development, such as drawing a line of demarcation between the latter and production, or distinguishing among the components of R and D, which must be emphasized in this sectoral survey. As regards the field breakdown, the use of relatively broad categories is sufficient for basic research, including the life, physical and mathematical, engineering, and other sciences, followed by their main subdivisions. A question arises in the case of the social sciences, since relatively little research is carried on in the latter by private concerns, so that some countries have found it advantageous to exclude them. It should be pointed out that marketing research, the taking of public opinion polls, and the like are excluded on the ground that they are connected with data collection and are thus outside the scope of R and D.

70. A different approach may be taken with respect to a field breakdown of applied research and development in the survey of the business enterprise sector. Instead of classifying the two components by the engineering and other applied sciences, it is more advantageous to resort to a breakdown by the end results, namely, the various product fields covered by the work. This system is followed in the United States, which has developed a relatively detailed list of product fields, as follows:

Aircraft and parts . . . .
Atomic energy devices . . . .
Chemicals, except drugs and medicines . . . .
Industrial inorganic and organic chemicals . . . .
Plastic materials and synthetic resins, rubber and fibers . . . .
Agricultural chemicals. . . . .
All other chemicals . . . .
Drugs and medicines . . . .
Electrical equipment, except communication . . . .
Electric transmission and distribution equipment . . .
Electrical industrial apparatus . . . .
Other electrical equipment and supplies . . . .
Communication equipment and electronic components . . . . .
Fabricated metal products . . . .
Food and kindred products . . . .
Guided missiles and spacecraft . . . .
Machinery . . . .
Engines and turbines . . . .
Farm machinery and equipment . . . .
Construction, mining, and materials-handling machinery . . . .
Metal-working machinery and equipment . . . .
Office, computing, and accounting machines . . . .
Other machinery, except electrical . . . .
Motor vehicles and other transportation equipment . . . . .
Motor vehicles and equipment . . . .
Other transportation equipment . . . .
Petroleum refining and extraction . . . .
Primary metals . . . .
Primary ferrous products . . . .
Primary and secondary non-ferrous metals . . . .
Professional and scientific instruments . . . .
Rubber and miscellaneous plastic products . . . .
Stone, clay, and glass products . . . .
Other product fields . . . .
Other ordinance, except guided missiles . . . .
Other, not elsewhere classified . . . .

It will be seen that these product fields are closely related to the industrial classification, but they focus on specific groups of items, thus resulting in figures that are relatively more homogeneous than those developed by the industry grouping.

71. The geographical distribution of research and development expenditures is also important in the business enterprise sector. Regional and local associations of industry and commerce, as well as individual concerns, are often interested in the relation of industrial R and D performance to the economic

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development of specific areas, so that a geographical breakdown in the data will supply an important need in this respect. The extent to which such statistics should be compiled will depend on the size of the country, and steps should be taken to make them available for both states and provincial areas and metropolitan sub-divisions.

72. There are some special aspects in the survey of the business enterprise sector with reference to extramural and intramural expenditures. As a performer of research and development, this sector draws its funds from two sources, namely, financing from the central government and support from the industrial companies proper. At times, the R and D funded by the Government may be shifted by the prime contractors to sub-contractors, or the companies financing their own R and D may have the work performed by other concerns within the sector, but these are intrasectoral transfers of funds and do not affect the total picture of industrial performance. On the other hand, the business enterprise sector sometimes will finance R and D to be performed in higher education or in some of the miscellaneous non-profit institutions. All these distinctions should be reflected in the data collected from industrial concerns, as a basis for showing both the intrasectoral and intersectoral flow of funds.

73. Some additional points should be kept in mind in the statistical reporting of resources devoted to research and development in the business enterprise sector. One relates to capital expenditures in some companies, which find it difficult to allocate this item as between R and D and other operations, due to joint uses of the plant and equipment by several functional activities. In such cases, the respondent should be asked to make an arbitrary allocation to R and D, using some logical method that yields a reasonable estimate. In private industry, there is also a significant number of employees devoted to both R and D and other functions, whose time records have to be converted to full-time equivalent units and added to the number of actual full-time employees engaged in R and D. Furthermore, there are a number of concerns carrying on R and D abroad, either maintaining their own laboratories or contracting the work to foreign concerns. As in the case of the government sector, this survey should cover separately the resources devoted to the foreign operations, which is important in the international analysis of R and D. Lastly, the survey should

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require certain over-all data pertaining to individual concerns, such as total employment and net sales and receipts.

74. It is possible to make considerable use of various ratios computed from the basic data obtained in the survey of research and development in the business enterprise sector. Thus, from the statistics of salaries and wages and manpower, one can compute average earnings of scientists and engineers, technicians, and supporting personnel, which are valuable in making comparisons as to labour costs involved in R and D. The average expenditure of R and D per scientist and engineer is an essential figure in decision-making as regards future budgetary allocations. Lastly, by computing the average expenditure of R and D per employee, or by relating R and D to net sales, one can throw considerable light on the intensiveness of the R and D programmes. All these ratios can be computed by industry and size of company, which enhances the analysis of the over-all data, and it enables individual companies to make comparisons between themselves and their respective categories. This is significant in a competitive situation, such as is prevalent in the business enterprise sector, where R and D is playing a major role in the economic prosperity of concerns, industries, and the economy as a whole.

3. Surveys of research and development in the non-profit sectors

75. Surveys of research and development in the non-profit sectors of the economy also have some unique characteristics, whether one deals with higher education or the various kinds of miscellaneous non-profit institutions. In fact, it is difficult to treat all of these segments in the same manner in the compilation of R and D data, and special adaptations must be made in each case.

76. The survey of research and development in higher education is a formidable undertaking, especially in a large country. One should aim at a complete coverage of all institutions, although in the United States, in view of the great number involved, the inquiry is limited to the large- and medium-sized schools, which is augmented by a sample of the small colleges. One difficulty in the compilation lies in the fact that the institutions of higher learning are generally backward in record-keeping to supply the necessary data, and besides faculty members and administrators are often annoyed by requests for detailed information. This difficulty may be overcome by frequent consultations with the school representatives

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in the course of the work, but on the whole it is possible to apply the mail-questionnaire method of inquiry. The survey should be repeated at regular intervals, perhaps every two or three years, with the ultimate objective of establishing annual collections.

77. It is understood that the survey of research and development in higher education should be limited to its science-oriented branches, and one of the major requirements is a breakdown of the data by broad categories of institutional specialization. Although the organizational structure varies both within a country and from one country to another, it is possible to compile figures by such categories as liberal arts and science, engineering, medical, agricultural, and other institutions, whether existing as affiliates of large universities or as independent schools. Some countries may have unique organizations, such as the Federal Contract Research Centers connected with universities in the United States, and special care should be taken to provide a separate treatment of the activities in the latter.

78. Relatively little of the research performed in this sector is financed from the regular budget of the institutions of higher learning. Some of this work consists of special projects for which separate funds have been set aside in the school. There is also a certain amount of departmental research, funded out of the budget allocated for both teaching and research in a given department. This element used to play a major role, but in recent years it has declined considerably. At present, most of the research in higher education is supported by outside agencies and individual gifts, financed by the Government, business enterprises, private foundations, health agencies and similar bodies. It is essential that the sources of the funds be summarized by sectors and their sub-divisions.

79. Several other points should be noted with respect to the expenditures for scientific research performance in higher education. Thus, in compiling data on current operating funds, special care must be exercised to exclude any research covering the non-scientific fields, such as the humanities, law, and theology, wherever they may be located in terms of organization. Likewise, it is necessary to scrutinize the indirect costs, which cover all activities in the school, including non-scientific research, teaching, and other functions, so that the current operating expenditures will include only the share applicable to the

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research in the scientific fields. This is particularly important in outside sponsored research, especially emanating from the Government, that may not make a full allowance for indirect costs, in which case the amount contributed by the university should be added to the current operating funds. Lastly, due to the joint uses of some buildings for both research and teaching in the sciences, it will be necessary to make an estimate of the capital expenditures applicable to scientific research, as indicated previously.

80. As in the Government and business enterprise sectors, the research and development expenditures in higher education should be classified by geographical areas. Likewise, there should be a breakdown of the data by fields of science, using the relatively broad groupings mentioned before. Lastly, any funds devoted to research abroad should be reported separately, including a breakdown by field of study and country in which the work is performed.

81. The measurement of scientific manpower is an important element in the surveys of higher education, especially as related to scientists and engineers. As already noted, most of the latter are engaged not only in research but also in teaching and other activities. Thus, it becomes necessary to determine the time devoted to research in each case, converting the figures to full-time equivalents, which must be added to the number of full-time employees. The computation of the time devoted to research is a laborious task, to be performed by the individual researcher or estimated by some responsible administrator, but it needs to be done only for one representative period during the year. There are similar complications with respect to laboratory assistants and technicians, many of whom are graduate students and in addition to research are engaged in studying and teaching. Such persons should also be required to keep a time record of their research work, under the supervision of their principal investigators, for conversion to full-time equivalents in compiling the total number of research technicians. The manpower data on research should also cover the supporting personnel, most of whom are full-time workers.

82. In dealing with the sector covering the miscellaneous non-profit institutions, the survey must be adapted to the situation in the country, depending on the types and number of organizations in existence. All segments of the sector should be covered simultaneously, but the questionnaires will need to be varied to some

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extent, even though the basic inquiries will apply in all cases. Generally, the coverage should be on a 100 per cent basis, except in segments with large numbers of small units, where it will be necessary to resort to sampling. Again, the mail-questionnaire method will be found quite appropriate, although it will need to be supplemented by other contacts to take care of special problems. As regards the frequency of the survey, there is always the temptation to spread the interval, but it should be repeated as often as the inquiry in higher education.

83. Limitations of space do not permit any discussion here of the problems peculiar to each segment of the miscellaneous non-profit sector, but the breakdowns used in the data should, in so far as possible, correspond to those in the other sectors. This applies to such items as type of research, fields of science, current operating v. capital expenditures, intramural v. extramural finances, geographical areas, foreign activities, and manpower. In this connexion, it should be remembered that, whereas each segment may fulfil a special function, its corresponding resources involved are quite limited. Yet, added together for all segments in the sector, the totals are significant and help to complete the over-all picture for R and D in the country.

B. Compilation of national statistics in research and development

84. Following a discussion of the sectoral surveys, the next step is to describe the integration of the statistics to present an over-all picture of research and development in the country. In this connexion, a distinction should be made between the variables peculiar to a given sector and those applying to all sectors. The latter involve breakdowns by type of research, field of science, and geographical areas, and obviously the national analysis must be restricted to these variables. This analysis and grand totals obtained for the country cover both financial and manpower resources devoted to R and D in the nation as a whole.

85. In summarizing the research and development data in a country, primary emphasis should be given to current operating expenditures, especially as regards the relation between extramural and intramural funds. As pointed out previously, an organization may play a double role in connexion with R and D, being a

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financer of the activity or source of funds and a performer of it or user of funds. Moreover, the degree to which these roles are carried out varies considerably, some organizations being essentially financers, others primarily performers, and still others combining the two functions in R and D. Accordingly, the aggregating of the data must be accomplished in a manner that takes into account these complementary functions and the involved financing-performance division of labour among the sectors of the economy. This necessitates a presentation of the intersectoral flow of funds, which may be done by means of a double-entry arrangement or matrix, sometimes referred to as a "transfer table". Such an approach minimizes the possibility of double counting, thus improving the accuracy of the data.

86. The contents of the transfer table, covering imaginary data in a single year, are as follows:

Intersectoral Transfers of Funds Used for Performance of R and D, 1965

Sector		R and D Performers (Millions of monetary units)					Percent distribution
		Government	Business enterprise	Higher education	Miscellaneous non-profit institutions	Totals, by source	
		(1)	(2)	(3)	(4)	(5)	(6)
Sources of R and D funds	(1) Government	2,000	4,000	400	100	6,500	65
	(2) Business enterprise	-	3,000	50	50	3,100	31
	(3) Higher education	-	-	250	-	250	2.5
	(4) Miscellaneous non-profit institutions	-	-	50	100	150	1.5
	(5) Totals by performer	2,000	7,000	750	250	10,000	
	(6) Percent distribution	20	70	7.5	2.5	100	

As shown above, the columns in the table represent the sectors as performers of R and D, whereas the stubs show them as sources of funds. The data contained in the table are hypothetical, including absolute figures with the totals distributed by percentages. This table is based on R and D performance totals collected from respondents, showing the amounts obtained by them from various sources. However, a similar table could be evolved on the basis of the R and D funds the various organizations allocated (as sources) to recipients, giving the information to whom they transferred the amounts. The latter approach would reflect the funds obligated or set in motion for, rather than consumed in, R and D. Each of these tables could be used to cover all R and D expenditures, as well as the figures for one or more of its components, namely, basic research, applied research, and development. The advantage of this presentation is that it shows at a glance the financing situation of R and D, thus reflecting the role of each sector in the total activity in the country.

87. In order to analyse the annual data by fields of science or geographical areas for the country as a whole, it is sufficient to employ the totals for current operating expenditures in research and development, as reported by performers in the individual sectors. A tabulation by fields of science is desirable, but it should be done by broad categories of science, in order to enhance the accuracy of the figures, provided such statistics were obtained on a uniform basis in each sector. As regards geographical areas, the totals from the various sectors should be combined, thus obtaining a distribution for the entire country, which will be found useful in over-all studies of economic development by region.

88. On the basis of the sectoral surveys, annual totals may also be obtained for capital expenditures, which added to the funds used for current operations provides an aggregate for research and development in the country as a whole. These data may then be presented as a time series, showing the trend in total expenditures for R and D over the years.

89. Lastly, national manpower data for research and development may be compiled from the sectoral surveys. The most significant segment covers the full-time equivalent number of scientists and engineers, and the figures for the country as a whole constitute a significant time series for R and D.

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90. In view of the dynamic aspects of research and development, there is a need for making projections to cover future years. This is often connected with planning activities, both short- and long-range, and the prognostications are based on political, economic, and other considerations that are assumed will prevail in the years ahead. The projections should cover the financial and manpower resources required to carry out the future plans for R and D.

C. Limitations of research and development statistics

91. As stated before, in spite of the relative recency of statistical programmes in research and development, there has been considerable progress made as regards the scope and quality of the data obtained in various countries. Yet, there are numerous questions being raised with respect to the limitations of the figures, and this subject deserves special consideration in the current discussion.

92. One of the criticisms levelled at the current research and development statistics is that they are limited to work performed by organizations, thus omitting the activities of the independent inventors and consultants whose efforts often lead to important contributions. The chief reason for the exclusion of the latter is the difficulty of reaching them through a conventional statistical survey, since they cannot be located easily and besides would tend not to respond to questionnaires. As a result, the size of this group and the extent of the R and D activities of its members are not known, but it is felt that their efforts have been constantly diminishing over the years, and the omission does not affect materially the total figures. The same may be said of any scientists and engineers working in laboratories who spend their spare time on R and D. As will be recalled, there are even some organizational units whose work is left out from R and D statistics, such as provincial and local governments, departmental research in higher education, etc., although this can be remedied by extending the scope of the surveys in different countries.

93. An important source of error in statistical surveys in some fields stems from the restricted coverage used, but this tendency should be limited as regards research and development activities. As already indicated, the goal is a 100 per cent coverage for large- and medium-sized organizations in most countries, and the experience shows that as a result of initial and follow-up contacts the

final response rate may be advanced to very nearly complete coverage. Hence, the only sampling error in these surveys is in connexion with the small organizations, where the coverage is restricted to relatively small samples, and it becomes necessary to blow up the data to the total size of this segment. However, the role of the latter in the R and D universe is quite limited, so that any error due to sampling cannot affect the total figures to any significant extent.

94. By contrast, the research and development statistics are bound to be affected by response errors, due to the nature of the concepts and definitions used in the surveys, as well as the element of bias among respondents. The difficulties inherent in the process of categorization and quantification have been discussed throughout this paper, and they stem from the complex nature of the R and D activities, which are greatly involved both in terms of the abstract and practical points of view. From the pragmatic standpoint, it becomes necessary to draw arbitrary lines in the formulation of these concepts and definitions but their interpretation is in the hands of the respondents, who have wide differences of opinion that are reflected in the reporting of data. Nor should one overlook the bias of reporting organizations, as mentioned heretofore, which may be psychological, political, or environmental. Some R and D activities are surrounded with an aura, in order to impress stockholders or members of the national legislature. The academic environment in higher education is certainly reflected in the reports of the latter, especially as regards fields of specialization and related topics. To be sure, the reporting errors resulting from the above factors vary in extent and direction, but their net effect on the tabulated data can hardly be estimated.

95. Another problem connected with the statistical reporting of research and development is the lack of uniformity in the accounting principles and practices among the various organizations in each of the sectors of the economy. The R and D survey presents a specific framework for the reporting of data, but some of the respondents can only meet the requirement for the principal items, thus resorting to estimates in order to complete all parts of the questionnaire. It is difficult to determine the extent of such estimating within a sector, and the total margin of error involved is quite unknown. It is true that government surveys often influence the accounting of the respondents, who will make changes

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to satisfy the requirement of the questionnaire, but this process is very slow as regards immediate improvements in the accuracy of statistical data.

96. An effort can be made by the collecting agency in the course of the survey to minimize the response errors in the research and development statistics. First, it is essential to exercise considerable care in designing the questionnaire and the instructions sent to the respondents. It is advisable to use the shuttle form containing the data for the previous period as a guide, and the concepts and definitions must be stated clearly and concisely and reinforced with illustrative material. Second, the questionnaires must be edited in great detail, followed by contacts with any respondent to explain any radical deviations from previously reported figures. Third, the tabulation of the data must be in relatively broad categories, if necessary, in order to enhance the accuracy of the figures. Lastly, the analysis of the statistics in the final report must point out the limitations inherent in the latter, so that the reader will be safeguarded in the uses of the information. To be sure, these practices should apply to all fields of statistics, but they should be emphasized particularly in a relatively new area as R and D.

97. Likewise, it is important that the collecting agency adopt a long-range plan for the improvement of the research and development statistics. One is dealing here with a highly dynamic activity, which requires taking into account new ideas and problems that accumulate over the years. For this reason, there should be undertaken at regular intervals a comprehensive review of existing concepts and definitions and other survey aspects by a representative group of experts in the total area, so that the inquiries may keep abreast of the recent developments. Simultaneously, the collecting agency should continuously carry on educational work among respondents, particularly with respect to the interpretation of concepts and definitions, as well as guidance in instituting and modifying information systems that result in improved measurements of R and D and their ramifications. This can be done by means of rotating group conferences and other ways, whereby the agency and respondents keep in close touch with one another with the ultimate goal of improving R and D statistics.

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V. MISCELLANEOUS ASPECTS OF RESEARCH AND DEVELOPMENT STATISTICS

98. In concluding the discussion of research and development statistics, it is necessary to consider several other topics that have a bearing on this subject. One item deals with the efforts to deflate the financial data by means of an index of R and D costs, in order to clarify yearly trends. A second topic covers comparisons of R and D figures with other over-all statistics, as a basis for amplifying the importance of the former with respect to related variables. Lastly, there is the need for making international comparisons of R and D activities, thus throwing some light on the relative role of the latter among various nations.

A. Relation of research and development statistics to other selected variables

99. As important as research and development may be, they constitute only one segment of the totality of activities in the economy. Hence, in order to help evaluate the role of R and D, the latter should be related to other aspects of science and technology, as well as to some of the aggregate measures of economic activities, such as the Gross National Product or any of its components.

100. As will be recalled, there are a number of activities that are closely related to research and development, namely, mass data collection, dissemination of scientific information, and testing and standardization. The resources devoted to these activities are also subject to statistical measurement, and surveys may be conducted to cover them separately or as part of the regular R and D inquiries. The surveys of related activities are usually confined to the current operating expenditures involved, and they must be adapted to the particular problems inherent in each area. Since the greater part of the above activities is carried on by the national government, the inquiries thus far have been confined to that sector. Perhaps eventually, the surveys may be extended to include the remaining sectors, so that one could have national data for each of the R and D related activities. Although the total resources devoted to the latter are relatively limited, the availability of such data is important not only for the sake of each activity but to yield an aggregate figure for R and D <u>and</u> their related activities.

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101. Likewise, it is possible to develop a statistical programme to cover science education. Such statistics may be collected as part of surveys for total education in a country, or they may be compiled simultaneously with those of research and development in the various sectors of the economy. The inquiries would deal with such items as student enrolments and graduations, as well as with financial and manpower resources devoted to science education. Many of the procedures and problems encountered here are similar to those present in surveys of research and development. The existence of parallel data for both areas is of enormous value, as a basis for policy formulation and administration. As it is well known, one of the main issues is the proper balance between science education and R and D, in terms of the allocation of financial and manpower resources to each of the latter. Furthermore, it is interesting to add the resources devoted to science education and R and D and their related activities, in order to arrive at the aggregate for the entire area of science and technology. A few countries, especially the United States, have already begun to make statistical surveys of science education, but it will take considerable time before such a programme is generally adopted.

102. Since the research and development activities are closely linked to the stabilization and growth of the economy, it is customary to compare expenditures of the former with the Gross National Product. In making such a comparison, however, one should understand the nature of each series, especially the relation of one to the other as economic measurements. Thus, the GNP constitutes the market value of all the goods and services produced in a country, being an aggregative index of the output in the economy. However, it should be pointed out that, for the most part, the R and D expenditures, comprising salaries and wages and purchases of materials and supplies, are written off as current charges and conceptually their contribution to the GNP is reflected only indirectly in the value of final goods and services. Furthermore, the R and D funds are more in the nature of an investment affecting the output in future years. The R and D activities give rise to numerous innovations, including processes of production and goods and services that did not exist previously. In fact, the time lag involved between R and D performance and the final results varies considerably from

one situation to another, especially if one considers the basic research undertaken. In other words, whereas the GNP represents current output, R and D are considered a major factor in influencing the future product of the country.

103. Accordingly, in making comparisons between expenditures for research and development and the GNP or any of its components, the questions implied in the process are, in reality, to what extent are the former keeping pace with the latter, or how much R and D can the country afford in terms of its national output. The answers to these questions are given by computing both the funds devoted to basic research and total R and D as a percentage of the GNP over the years. Furthermore, basic research and all R and D expenditures, since they are considered in the nature of a long-range outlay, may be related to national investment, in terms of government purchases of durable goods and construction and gross private domestic investment less residential construction.

104. So far the discussion has been confined to financial comparisons, but a like analysis may be made also on the basis of manpower figures. Thus, the number of scientists and engineers engaged in research and development may be compared to data representing all scientists and engineers in the country over the years, using if possible the concept of full-time equivalent persons. Lastly, the total personnel working on R and D, including scientists and engineers, technicians, and supporting employees, may be related to the entire civilian labour force, which is an indication of the manpower contribution to these activities in the country.

B. International aspects of research and development statistics

105. There are numerous complications to the international aspects of research and development and their measurements. Although the discussion here has been confined to R and D statistics from a national standpoint, it should be recognized that the activities measured do not recognize the boundaries of individual countries. This fact is an important consideration in making international comparisons of R and D data.

106. In describing the surveys of research and development, the suggestion was made that separate figures be compiled for R and D financed in a given country but

performed abroad, showing the funds and manpower involved in each land where the activities were carried on. The practice of financing outside R and D is confined to a few countries, especially the United States, and it covers basic research and applied research and development. Thus, the above procedure would help avoiding any duplication in the making of international R and D comparisons.

107. By contrast, many countries supplement the output of research and development within their own boundaries by buying patents outright or licences to use them from other lands where the inventions are made. This demand is met by researchers in various countries, especially some of the smaller ones, which find it difficult to market the results of their work locally and advantageous to treat inventions as an export article. Except for counting the number of such patents and licences involved, there is no way of measuring the actual financial and manpower resources devoted to the R and D in this foreign business. Moreover, the international buying of patents and licences reflects only the activity in applied research and development, since the discoveries in basic research are widely published in scientific journals and books and are free to the scientific world.

108. However, the main consideration in this discussion, as regards the international aspects of research and development, is the making of general statistical comparisons among countries in connexion with these activities. The validity of the comparisons will depend on the extent to which the various lands employ a standardized approach in concepts and definitions and methods used in carrying out their respective programmes in compiling R and D data, although it is recognized that national peculiarities and conditions will limit the achievement of such an objective. As a result, it is probably wise to avoid detailed comparisons, limiting them to the over-all figures and their principal components. One of the main difficulties lies here in the inter-country differences in the real value of their currencies and the volume of their economic activities, which can be overcome by utilizing relative rather than absolute figures in formulating the comparisons. For example, the over-all picture should be based on the relation of R and D expenditures to the GNP in each case, thus showing the former as a percentage of the latter. A similar approach may be used with respect to manpower data, computing the number of R and D scientists and engineers as a percentage of the total group, or the entire R and D personnel as a percentage of the total civilian labour force in each country.

VI. MEASUREMENTS OF RESEARCH AND DEVELOPMENT OUTPUT

109. In general, there are three main approaches that have been proposed in measuring the output of research and development, namely, those involving publications, patents, and economic evaluation. Each of these is subject to considerable controversy as regards the methodology to be used and the adequacy of final results. The present discussion will be limited to a critical appraisal of these proposals in the solution of the problem of output measures.

110. Some writers in the history of science have recently used the volume of publications to illustrate the growth over the years. Likewise, a few analysts have employed printed materials as a measure of scientific output for individual companies and specific fields. There are numerous types of publications in science, such as books, monographs, official reports, periodicals, etc., but the tendency is to concentrate on counting the number of scientific and technical journals and their contents, i.e. the number of articles and the pages devoted to them. It is realized that many difficulties are involved in developing comprehensive output measures of R and D, in terms of coverage and the application of statistical techniques. Certainly, primary consideration should be given to the variety of scientific fields, as well as to the components of R and D. Another goal should be to develop the information by sectors and for the country as a whole. There is a constantly expanding number of periodicals, and one would have to resort to sample selections to reflect the universe, which would later require the use of proper weights to obtain data on a 100 per cent basis. There are numerous other methodological problems to be solved in the process, if one is to develop a reasonably meaningful index of publication output, although it is realized that the final measuring stick will always be subject to considerable limitations. Some exploratory work has already been done in this area, but it is certain that the achievement of the final goal is in the distant future.

111. One of the main considerations in constructing an index of research and development output is the problem of quality of the periodicals and articles to be included. Special care should be exercised in selecting the scientific and technical journals, thus making sure that they are well recognized by professional societies and the scientific community at large, but perhaps the judging of the

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quality of individual articles should be based on their acceptance by the editorial boards of the respective periodicals. Another factor to consider is the tendency on the part of some researchers to publish two or more articles on the same findings in different journals, and an attempt should be made to minimize such duplication. Lastly, it should be remembered that the scientific findings of articles are not all equal in importance, some being relatively minor and others revolutionary in character. It is difficult to deal with this problem, although one analyst has suggested using the number of citations of an article as a measure of differential significance of the scientific results.

112. As a measure of research and development output, patent statistics in a country are also subject to serious limitations. For one thing, being a by-product of an administrative process carried on by the national patent office, the data tend to be routine in nature and limited to a few breakdowns. In compiling the figures, the main goal is to be enumerative rather than analytical, as a basis for describing past workloads in connexion with the operations of the agency. Thus, a distinction is made between patents pending and patents granted, classifying each as having originated from either individual inventors or corporations, and frequently the patents are grouped together into classes representing like characteristics. Since hardly any patents emanate from basic research, the output of the latter is almost entirely omitted in the statistics. Furthermore, there are even limitations in using patent data to represent the results of applied research and development. Some individual companies do not have their inventions patented for various reasons, such as failure to obtain patent approval, a desire not to be involved in the costly process of obtaining a patent, fear of being accused of monopolistic tendencies, etc. Also, a number of inventions represented by patents are never used, due to such factors as lack of capital and concern over the profitability of the venture. Lastly, the statistics treat all patents alike, whether they represent minor and insignificant modifications of old inventions or are so revolutionary in nature as to produce vast changes in the technology. One advantage of patent data, however, is that they do cover the individual inventors working independently in addition to the organized R and D programmes in corporations, but the recent trend has been a decline of the former as compared with the latter category, which has already been pointed out.

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113. On the other hand, there are many potential and actual uses that may be made of patent statistics as an output measure of research and development. Working in collaboration with officials of the national patent office, one may introduce improvements in the figures. It is feasible to develop on an arbitrary basis patent totals for sectors and their subdivisions. For example, in the business enterprise sector, the patents may be classified according to the industry in which their utilization is contemplated, or by size of company, etc., which makes it possible to correlate their number with R and D resources and other economic variables. On the basis of mail questionnaires, it is also practicable to follow up the over-all patent statistics with special surveys covering specific problems in the analysis, a procedure that has been undertaken in a number of cases.

114. The use of economic evaluation as a measure of the output of research and development is largely a matter of detailed analysis of data from a variety of sources rather than the over-all compilation of statistics. This analysis may be applied to a single invention, such as the diesel engine or computer, showing how each of these has benefited the economy or any part of it. Analytical studies have been made to describe the extent to which R and D has contributed to the growth of a particular company, an individual industry, or all industrial activities in the business enterprise sector, in which profit motivation is an important factor in stimulating technological and economic development. Such analysis is complicated in the other sectors, but it is employed in studies of stabilization and growth of the economy as a whole. As in the case of all economic analysis, one is confronted here with numerous difficulties in obtaining conclusive results, due to the large number of variables involved, the limitations of the data, and the inadequacy of the methods used. Yet, the effort is important in relation to an understanding of the functioning of the economy, in order to engage in future planning and activities.
