studies on scientific and
technological development - no. 7

A SYSTEMS APPROACH TO SCIENCE AND TECHNOLOGY POLICY-MAKING AND PLANNING

Regional Scientific
and Technological Development Program
Department of Scientific Affairs
General Secretariat of the
Organization of American States
Washington, D.C.

A SYSTEMS APPROACH TO SCIENCE AND TECHNOLOGY POLICY-MAKING AND PLANNING

Regional Scientific and Technological
Development Program
Department of Scientific Affairs
General Secretariat of the
Organization of American States
Washington, D.C.
1972

This study has been prepared by Francisco Sagasti, Specialist in the Division of Planning and Studies of the Department of Scientific Affairs of the General Secretariat of the Organization of American States. It is based on a similar work of this author published in July, 1970.

STUDIES ON SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

Introductory Note

Science and technology are becoming increasingly important for economic and social development. Industrialized countries have recognized this fact in two ways: 1) by devoting an increasing volume of investment funds to research, experimental development and the training of specialized personnel, and 2) by systematically studying scientific and technical problems with a view to formulating explicit policies for such development.

Similar, though still insufficient, efforts have been undertaken in developing countries, where planning the use of scarce resources is even more necessary. All basic research activities providing knowledge on the technical development process, on the policy and planning aspects of technical development, and on the operation of the scientific and technological system contribute greatly to the ability of those countries to organize scientific and technical activities systematically in terms of economic and social development requirements.

The OAS Inter-American Committee on Science and Technology urged at its Sixth Meeting held in December 1970 that a series of publications in this field be started. For this reason, the Planning and Studies Division has undertaken a preliminary publication of the findings obtained from a number of technical meetings and research work the Division has carried out and sponsored. It is hoped thus to establish a dialogue between researchers and planners, to encourage their comments and to stimulate fresh contributions to studies on science and technology in Latin America.

Organization of American States
Department of Scientific Affairs
Planning and Studies Division

TABLE OF CONTENTS

LIST OF FIGURES

PREFACE

This report constitutes an attempt to introduce the "systems approach" or the systems "way of thinking" to the problems involved in policy-making and planning of scientific and technological activities.

It begins by suggesting a conceptual model of the nation as a system, which constitutes the frame of reference for the analysis of scientific and technological activities, relating them to other functions and activities in the nation.

Then, in Part II, a detailed analysis of the scientific and technological sub-system is made. It is treated as a system whose primary function is to generate and modify the intangible good "knowledge". All the activities that affect this flow of knowledge are identified, together with the institutional patterns that group them and the way resources are channeled to Scientific and Technological activities. Part III studies some of the implications of this "systems" point of view.

The fourth part of the report contains a review of the relevant literature on the subject of scientific and technological policy-making and planning. Particular emphasis was given to an analysis of planning methods proposed by other autors.

The fifth part contains a brief analysis of the characteristics of an idealized planning methodology and the steps that would lead towards its realization.

A SYSTEMS APPROACH TO SCIENCE AND TECHNOLOGY POLICY-MAKING AND PLANNING

PART I: An Analysis of the Nation as a System

I. Introduction

A system can be defined in the most general sense as a collection of interrelated entities each of which affects, at least potentially, the behavior of the others. According to this definition, a nation state could certainly be considered as a system, and here we shall take the nation-system at large as our frame of reference in the analysis of the Scientific and Technological (S & T) subsystem. We shall also define some additional subsystems, covering our frame of reference, which are of special importance to the S & T subsystem. *

Previous attempts to define the nation-system have been made, among others, by Gross (1966), Parsons et al.(1951 and 1961), Parsons (1966) and Isard (1969). Each of them takes a different perspective and defines the nation-system in ways that are better suited for the purposes of their research. The task of cutting through the web formed by the multitude of relationships, institutions, individuals, elements, interactions, etc., found in a nation is not an easy one. Systems do not exist on their own, they are a product of the mind of the researcher as well as the entities he purports to investigate. Ultimately, the usefulness and success of a particular conceptualization of the nation as a system will depend on its fruitfulness, expressed in terms of the kinds of questions it poses and the hypothesis it suggests to the researcher.

Our conceptual model of the nation-system (and of the scientific and technological system) will be geared toward the study of science and technology policy-making and planning. Therefore, the guiding criteria for including or leaving something out when defining these systems will be based on the potential usefulness of the definition they would head to.

The importance of taking the system view when analyzing science policy has been suggested by Ackoff (1968 a):

> "... It is necessary, therefore, to develop an understanding of the functional relationships within the subsystem of science, and between science and other social subsystems. Such understanding must come from an analysis of structure and functioning rather than from intensive and

---

* For the sake of brevity we shall call these subsystems simply "systems" in the remainder of this paper.

extensive description. In brief, social planning requires theory as well as fact; without theory, it is like sex without a partner..." (p. 85).

This systemic view of science and technology has also been considered by Trist (1969), Vickers (1969), Dror (1969), King (1968) and Gargiulo and Moya (1970). Here we shall take a similar point of view focusing centrally on the scientific and technological system.

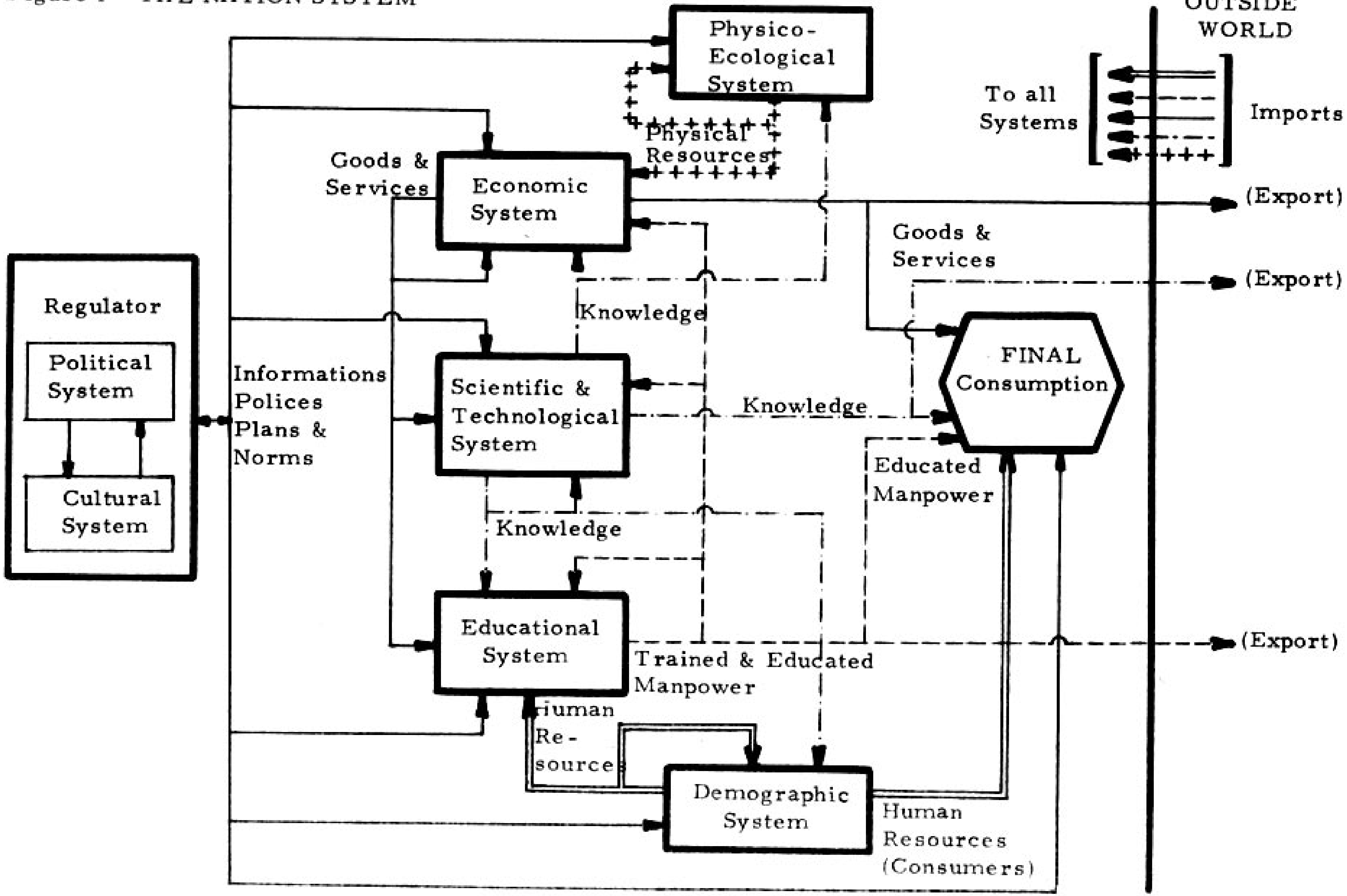
The diagram of Figure 1 shows an initial conceptualization for the nation-system and its various components. Each box represents a component system and the different flows between them are indicated by different types of lines. We shall consider five "operating systems" (physico-ecological, economic, scientific and technological, educational and demographic) and two "regulatory systems" (political and cultural).

The scientific and technological (S & T) system takes goods and services from the economic system, trained human resources from the educational system and knowledge from itself as inputs in order to produce its output in the form of more knowledge. The educational system takes its inputs from the economic, the S & T and the demographic systems in the form of goods and services, knowledge, and human resources respectively, combining them to produce trained human resources.

The economic system takes natural resources from the physico-ecological system together with knowledge from the scientific and technological system and human resources from the educational system, in order to produce its output of goods and services. The physico-ecological system provides the natural resources which are used by the economic system. Finally, the demographic system provides human resources which are an input to the educational system, and it also generates the consumer force in the nation-system, to which the outputs of the economic, scientific and technological, and the educational systems are ultimately directed.

In each of these systems there are crucial choices to be made. This is particularly true of the three central systems, the economic, the S & T, and the educational systems. The proportion of goods and services to be directed from the economic system to the other systems and the proportion devoted to final consumption has, in some way or other, to be established. Similarly, the proportion of knowledge produced by the scientific and technological system which can be considered as oriented to final consumption and the proportion designated to serve as input to the other systems has to be determined. Even in the physico-ecological and the demographic systems we find complex choices referring to the rate of exploitation and replenishment of natural resources and to the rate of growth of population.

Figure 1 - THE NATION SYSTEM



In addition to these choices, the matters are complicated even further by the fact that the nation-system is not a closed system. It exports and imports, not only goods and services, but also knowledge in all its forms, trained manpower, and natural resources. The regulation of these flows within the system (and in and out of it) is a task which is usually accomplished, implicitly or explicitly, by the political and the cultural systems, which act as regulators.

Thus the regulating systems may be considered as being interconnected with all the other systems in the nation; they receive information flows and generate a flow of policies, plans and norms. When regulation is achieved through explicit action, it generally can be considered as emanating from the political system; while the cultural system acts in the general case, as an implicit regulator; cultural norms and values can either inhibit or foster certain types of flows and activities in the nation-system.

So far we have taken a highly aggregate view of the systems within the nation-system, it is clear that each of them could be further subdivided. For example, the educational system can be partitioned into several smaller subsystems dealing with particular aspects of the educational activity, if this were done, only the higher education subsystem is likely to have its inputs directed to the scientific and technological system. The economic system could be subdivided taking into account different sectors of economic activity, and it would be clear that the physico-ecological system would feed mainly into the primary economic activities sector, rather than to the secondary and tertiary sectors of the economy.

Rather than subdivide further each of the systems considered here, we shall describe each of them in turn focusing on their interaction with the scientific and technological system, which is our main concern in this study.

However, before proceeding with our analysis we must caution that only the main flows between systems have been considered here. It is quite plausible that these systems could have some additional effects on each other, although these second-order interactions would be weaker than those depicted in Figure 1.

2. The Regulating Systems

The regulator of the nation-system contains both the political system and the cultural system. These would correspond to Parson's goal -attainment and pattern-maintenance systems respectively. The political system has the functions of generating goals, evaluating alternatives, and setting priorities. It also has power in the form of political influence; it exercises authority and mediates the interests of individuals, groups and institutions of the nation system. The cultural system, on the other hand, has the function of maintaining the stability of the nation system and legitimizing activities and flows within it.

Cultural norms and values are the forms through which the cultural system expresses itself and acts on the other systems. This system is also concerned with restoration of balance once the forces of change have modified the stability of the nation-system.

The operative systems in the nation-system are not passively affected by these regulating systems. They in turn modify and affect them and are, in fact, capable of influencing the types of regulation and the direction of regulatory actions. Furthermore, these two regulating systems do not act independently: cultural norms and values influence the plans and policies of the political system, but in turn, plans and policies can be directed toward changing cultural norms and values.

We shall now examine in further detail the relations between the regulating systems and the scientific and technological system, which constitutes our main concern here.

The Cultural System

The cultural system is related to the scientific and technological system in two ways: First, cultural values and norms limit the extent to which scientific and technological advances are introduced and diffused through the nation-system. This is particularly true for societies where there has not been a scientific tradition; for example, Baranson (1969) points out that:

> "Social organization, cultural values, and behavioral patterns have a direct bearing upon a society's willingness and ability to adapt and absorb technology. Attitudes toward authority and change, achievement motivation, and the desire for material gain have an impact upon labor productivity and labor proficiency. The propensity to innovate and take risks and a belief in scientific method are basic ingredients of the entrepreneurial function in technological transformation." (p. 356)

Second, the S & T system affects the society's cultural norms and values; it is not just passively conditioned by them. Referring to underdeveloped countries, Waldo (1969, p. 34) states quite sharply that "... there strikes me as being a great deal of naivete and dishonesty (however well-meaning) in the assumption that developing countries can "insert" science and technology into their cultures and expect them to remain their cultures." There is no doubt that the activities within the scientific and technological system can and usually do have, a great impact in the cultural systems of less developed nations. This connection between the S & T and the cultural systems should not be ignored.

The two types of links between these two systems can be conceptualized as an exchange of "cultural norms and values", an intangible good which is an input of decisive importance for the activities of the scientific and technological system: a positive attitude toward science and technology, or the existence of cultural norms and values which foster the development of science and technology, can be considered as a necessary, although not sufficient, condition for the development of the scientific and technological system.

The ways in which this intangible good "cultural norm and values" is traded between the cultural and the S & T systems are by no means simple. Direct cause -effect relationships are practically impossible to establish and the pattern of interactions is not only complex but also diffuse.

One example of these indirect and complex interactions is given by those activities aimed toward improving the prestige and acceptance of science in developing countries. They can be considered as an attempt at modifying the cultural system so that the cultural norms and values become positively oriented toward science and technology. Using Sommerhoff's (1950) conceptual framework they would be seen as an attempt to make the cultural and the S & T system "directively correlated" with each other. Powell (1966) expresses clearly the need for affecting the cultural system through scientific activities:

> "... In many developing countries there is an established tendency to train people in the arts rather than in the sciences. Law and politics are often the quickest way to wealth and fame for an intelligent young man, as they were in Europe in the eighteenth and nineteenth centuries. In such a situation it is particularly important to increase the prestige of the science and, from this point of view, it can be damaging to say that the higher flights of science are not yet for developing countries. Gifted people going into the sciences can do great things, not so much for themselves as for their people. The achievements of many distinguished Indian scientists, such as Bose and Raman, to mention only two, relieve a load of imposed inferiority and do much for the prestige of science and for the self confidence of their country." (p. 108)

In short: the grounds that justify the inclusion of the cultural system in our analysis are based on its interactions with the S & T system in terms of culture and norms, which can foster or inhibit the growth of science and technology in society.

The Political System

The political system has the general function of explicitly regulating the nation-system and of providing some services to it. The political and executive activities are included in this system which is concerned both with the establishment of rules and regulations, and with the enforcement and control of them.

One of the main functions of this system is the setting of priorities and goals which are expressed in terms of policies. It follows that one of the most important interactions between the political and S & T systems takes place through the definition of a scientific and technical policy which would guide the activities of the S & T system and its relations to other systems in the nation.

A second line of interactions is provided by the scientific and technological system's role as a provider of knowledge in the form of advice to the political system. With the growing complexity of modern society this role has acquired particular importance, especially in the highly developed nations of the world. Don K. Price in the The Scientific Estate gives a serious analysis of this relation between the two systems. However, this second area of interaction is probably of lesser importance in underdeveloped countries, where the activities of the S & T system have not permeated the nation-system in such a pervasive way.

Finally, as long as we are including government within our political system, a flow of financial resources must be included among the sources of interaction. The political system provides the scientific and technological system with resources for carrying out some of its activities.

Summarizing, we can state that the relation between the S & T system and the political system takes place through the flow of policies and resources from the political to the scientific and technical fiscal system, and through the flow of advice and influence from the S & T to the political system.

3. Relations Between the S & T System and Other Operating Systems

We now turn to analyze the interactions between the S & T system and the other operating systems in the nation. We shall begin with the educational, then proceed to the economic and the physico-ecological, ending with an analysis of the relations between the demographic and the S & T systems.

The Educational System

This system comprises all the organizations, institutions, and individuals engaged in the preparation and training of human resources for the nation-system. It is usually taken into account by most studies of science policy and its influence on the S & T system is widely acknowledged.

The educational system is related to the scientific and technological system in two ways. First, it supplies human resources to the S & T in the form of trained manpower and second the educational system plays an important role as a vehicle for diffusing knowledge through the nation-system. This dual pattern of interaction has been pointed out by Halty (1966):

> "... the human factor is essential in the entire scientific and technological planning process inasmuch as, on the one hand, human resources constitute an input to the scientific and technological sector and, on the other, the system's product, knowledge, is an outgrowth of the human mentality... " (p. 9)

The importance of the relation between these systems has been emphasized by various researchers. Among them, Simmons (1967) offers a concise review of the literature on the relation between technical progress and education. Powell (1966, pp. 102-103) provides an example of the typical statements found in the literature:

> "... It appears essential for all countries, as especially for those newly developing, to make a critical scrutiny of all forms of education....
>
> The proper content of education, a correct balance between primary secondary and higher education, between different types of institutions of higher learning, the relative weight given to science and technology, to "pure" and "applied" science, all pose difficult problems to a country which, if not satisfactorily resolved, may have grave social consequences."

In brief, the interaction between the S & T and the cultural system takes place through the exchange of human resources and the exchange of knowledge. On the one hand, the scientific and technological system receives trained manpower from the educational system, while on the other it generates and provides knowledge which is diffused through the educational system.

The Economic System

All the activities, organizations, individuals and institutions dedicated to the production and distribution of goods and services belong to the economic system. The general function of this system is to provide the members of the nation-system, whether individuals, organizations, or institutions, with the instruments they require for the pursuit of their objectives.

The relations between the economic and the scientific and technological systems have been widely studied and it is here that we find the largest (and most confusing) amount of literature referring to science and technology. The basic pattern of interaction between these two systems considers the S & T system as providing inputs to the economic system in the form of technological knowledge, which allows it to produce goods and services in a more efficient way. This is to say that the S & T system provides the economic system with the capability to generate more instruments more efficiently. The economic system, in return, provides the S & T system with material resources which ultimately can be referred to some monetary unit.

The current view of the relation between the S & T and the economic system, is summarized by Nordhaus (1969, p. 8) as follows:

> Even though little is known with great confidence about the role of technology in the economy, a set of generally accepted beliefs or stylized facts has been developed. . . .
>
> The most important stylized fact of technology is that technological change is the major source of growth of per capita income.

If we consider the income per capita as an indicator of availability of instruments in the nation-system, Nordhaus' remarks can be interpreted as saying that technological advance is the single most important source of increased instrumental availability for the individuals, organizations and institutions in the nation-system.

It is not surprising then, that most of the evaluations of the activities involved in the scientific and technological system, and in particular those related to technical change, are usually done in terms of their effect on the economic system, often neglecting their infuence on the other four we are considering here. The work of Nordhaus (1969), Spencen and Woroniak (1967), the Department of Scientific Affairs of the Pan American Union (1968), Fawcett (1969), and Libik (1969), among others, dwell only on the economic effects of scientific advance and technical change, although most of them acknowledge that they are dealing with only one of the multiple relationships that the S & T system has with other subsystems of the nation-system.

In conclusion, the relation between the economic and the scientific and technological systems has been widely and intensively studied in the past. The exchange between these two systems takes place in the form of technical know-how transferred from the S & T system to the economic system, and in the form of a flow of funds in the opposite direction.

The Demographic System

This system has the function of providing a base of human resources to the nation-system. It is constituted by all the individuals in the nation-system who participate in its activities in one capacity or another. Of particular importance is their participation as consumers, for in this capacity they act as recipients for the activities generated by all the other systems.

The links between this system and the S & T system are of two kinds: direct and indirect. The direct link is established through the influence that the knowledge generated by the scientific and technological system has on the demographic system, which can be very important particularly in the area of medical and health care. For example, the discovery of new drugs and antibiotics and their widespread application have reduced mortality rates to an impressive degree, with regard to this aspect Bhagwati (1966) points out that:

> The phenomenal decline in mortality experienced by some underdeveloped countries has been largely due to the application of modern science, through public health programs. In Ceylon for instance, the use of DDT is estimated to have reduced the death rate, previously stable for fifteen years, by 35% in two years! In Puerto Rico, Madagascar and India, the results have been equally impressive. (p. 90)

The indirect link is established through the educational system. The demographic system provides the human resources which are trained by the educational system and become inputs to the scientific and technological system. Another kind of link, which will be examined later, is represented by the flow of information in the form of problem areas that are suggested by the demographic system to the S & T system.

The Physico-Ecological System

This system is constituted by the physical and ecological environment of the nation-system and has the basic function of providing natural resources to the economic system, which uses them as inputs in the production of goods and services.

The physico-ecological system is also related to the S & T system through direct and an indirect link. The direct link is provided by those activities of the scientific and technological system which affect the availability of natural resources and their rates of exploitation and replenishment. Those activities aimed at prospecting the physical environment and preparing an inventory of natural resources are included here, as well as those oriented toward determining the best rate of exploitation and replenishment of perishable natural resources such as forests, wildlife and marine life.

The indirect link is established through the economic system which takes natural resources and transforms them into goods and services. These are in turn used by the scientific and technological system in order to produce its output of knowledge. Another type of link is found in the form of suggested problem areas for research or unique environmental conditions which allow particular kinds of research not possible elsewhere. (e. g. research in tropical agriculture).

4. Summary

Up to now our analysis of the scientific and technological system has proceeded from without. We began by studying the nation as a system and then looking at those subsystems that are directly related to the S & T system and by identifying these relations and interactions. Before starting with our detailed analysis of the internal functioning of the scientific and technological system, there are a few additional matters we must deal with.

In the first place, we must emphasize that the nation-system is not a closed system, for it clearly stands in interaction with other nation-systems. In particular, as long as science and technology are truly international in their nature, we shall consider explicitly the interrelations between the external world and the S & T system of our nation.

Secondly, Trist's conceptualization of the contemporary environment (1969) is of particular importance for our analysis. He distinguishes between the task environment and the contextual environment of a system:

> The task environment consists of all organizations, groups and people with whom the organization has specific relations, both on the input and output sides, even though it may not be aware of their complete range. The contextual environment consists of the relations which the entities included in the task environment have to each other and to other systems not directly entering the world of the organization's own transactions. Events in the contextual environment may at any time obtrude into this world, constructively or destructively, predictably or unpredictably. (p. 4807)

It can be inferred that four of the five systems we have defined, together the two regulating systems and the external world, constitute the task environment for the scientific and technological system. The contextual environment would be defined in terms of the transactions between the cultural and the political systems, the socio-demographic and the cultural systems, and so on.

A final remark before proceeding with our detailed analysis of the scientific and technological system. The usefulness of this exercise in systems definition will become apparent when examining the characteristics that a science and technology planning methodology should have. This analysis, in terms of systems and interrelations, will constitute a background against which to project possible methods for establishing science and technology plans, allowing better comparison among them.

PART II: A Closer Look at the Scientific and Technological System

1. Introduction

In Part I we gave an account of the environment within which the scientific and technological system operates. It was pointed out that the S & T system generates a flow of knowledge, taking inputs in the form of goods and services from the economic system, trained manpower from the educational system, problem areas and information from all the systems and directives from the two regulating systems. Here we shall take a closer look at the way in which the output of knowledge is generated within the scientific and technological system.

The scientific and technological system can be considered as a collection of interrelated operations and activities which generate and transform the intangible good "knowledge." The flows of different types of knowledge will be traced through the system and the activities that modify them will be characterized in terms of the informational inputs they take and the informational outputs they produce. In doing this we shall follow Machlup's (1962) description of research activities and types of knowledge.

Once we describe the flow of knowledge within the scientific and technological system, the "non-research" support activities will be studied identifying their relations to the other activities and flows in the S & T system. Then, we shall take a look at institutional and organizational arrangements which group one or more of these activities and describe the different forms in which they can be gathered, ending with and analysis of the flow of resources in the scientific and technological system.

2. The Flow of Knowledge in the Scientific and Technological System

The S & T system can be conceptualized in terms of knowledge flows and the activities that transform them. The diagram of Figure 2 shows these flows as arcs and the operations performed on them as nodes. The heavy lines indicate the main knowledge flows, the broken lines the secondary flows, and the broken-dotted lines show the flows of information in the form of problem areas and scientific requests posed to the S & T system.

Beginning with the flow of basic knowledge $[k_B]$ we see that it can be imported from the outside world $[k_B(i)]$ or produced within the S & T system through the activity called "basic research" (BR). The basic knowledge, internally produced or imported, feeds both into the activities of basic research and applied research. The main characteristic of this flow of basic knowledge is that it serves as input only to other research activities, and in particular, to the activity of applied research. *

* This is in agreement with the definition of fundamental (basic) research proposed by Ackoff (1966).

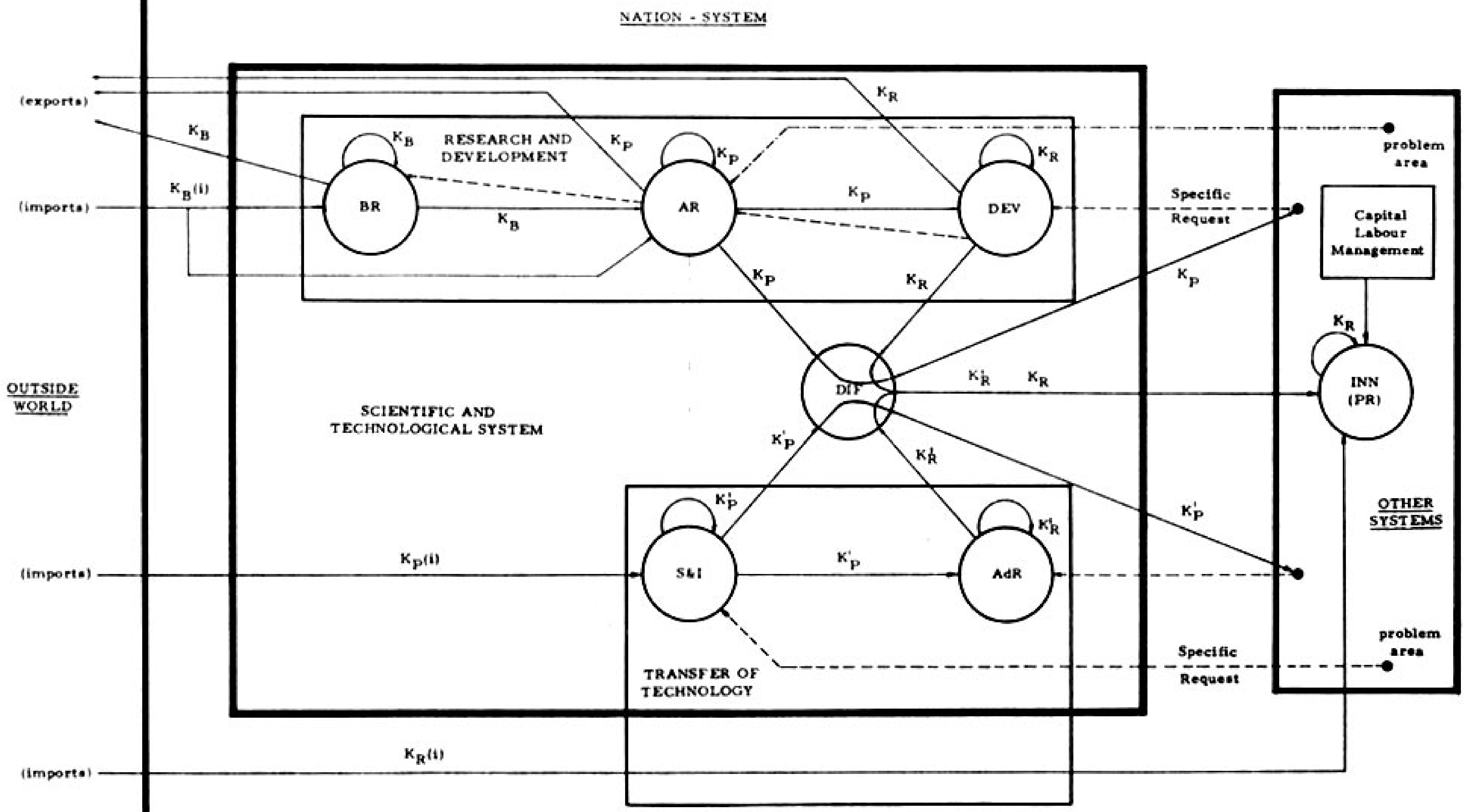


Figure 2. FLOW OF KNOWLEDGE IN THE SCIENTIFIC AND TECHNOLOGICAL SYSTEM

The flow of basic knowledge is transformed into potentially-useful knowledge [k_p] by the operation called "applied research" (AR). This operation takes as primary inputs basic knowledge (either imported or generated within the system), a problem area [pa] suggested by the S & T system or other systems, and also takes the potentially-useful knowledge generated by previous applied research activities. All of these are transformed into potentially-useful knowledge which, in turn, serves as an input to the diffusion and the development activities.

The flow of potentially-useful knowledge is conveyed to other systems in the nation through the "diffusion" activity (DIF). Once the potentially-useful knowledge generated by applied research reaches other systems which perceive a need for it, a specific request is submitted to the scientific and technological system, giving additional information about the concrete situation in which it is desired to put it in practice. This activity also takes the ready-to-use knowledge and feeds it into the innovation activity.

The activity called development (DEV) products ready-to-use knowledge (k_R) taking as inputs the flow of potentially-useful knowledge, the specific requests for its use [sr] and the stock of previously generated ready-to-use knowledge. Finally, the output generated by this activity is utilized in the activity called "innovation" (INN), which is generally outside the scientific and technological system and which is concerned with putting into practical use the stock and flows of knowledge generated by the scientific and technological system. This activity takes as inputs, in addition to the flow of ready-to-use knowledge, managerial skills, capital, and labor.

Three additional flows generated by basic research, applied research, and development, take the form of exports of basic, potentially-useful and ready-to-apply knowledge.

The activities of basic research, applied research, and development, constitute what is commonly gathered under the name of "Research and Development." However, for many nation-systems these activities do not exhaust the range of operations that are performed within the scientific and technological system. In the case of less technologically advanced countries, two additional activities play a prominent role: these are the "screening and identification" activity and the "adaptive research" activity.

The "screening and identification" activity (S & I), imports potentially-useful knowledge from outside the nation-system [$k_p(i)$] and selects one or more units of knowledge which would be particularly suited for the problem area posed to the S & T system. These selected pieces of potentially-useful knowledge [k_R'] are conveyed to the appropriate systems through the diffusion activity, and eventually generate specific requests to the S & T system. The activity of "adaptive research" (AdR) couples these specific requests with the potentially-useful knowledge from S & I in order to generate adapted ready-to-use knowledge [k_R^i] which, in turn, feeds into innovation (INN) through the diffusion activity.

Another activity which can be considered as belonging to the scientific and technological system, although it is not properly contained within it, is what we shall call "production research" (PR). This activity comprises all the operations performed to augment the flow of ready-to-use knowledge in one area of application, once the ready-to-use knowledge has been put into practice through innovation. For example, once a chemical plant has been installed there is usually an adjustment period during which experiments are performed, varying one or more conditions of the process, raw materials, etc., in order to determine particular combinations of these which increase the yield. Normal production schedules are generally maintained during these production research activities, which take the existing stock of ready-to-use knowledge already incorporated in the process in order to produce additional ready-to-use knowledge.

The secondary lines of information linking the applied research activity with the screening and identification activity and the development activity with the adaptive research activity, suggest that these two pairs of activities play similar roles using internally generated and imported potentially-useful knowledge respectively. In fact, arguments could be put forward for considering the activities of development and adaptive research as essentially the same, differing only in the sources of knowledge input they use.

Still, another flow of knowledge can be identified in the nation-system, although it takes place outside the scientific and technological system. This is the flow of imported ready-to-use knowledge [$k_R(i)$] which by-passes the S & T system and feeds directly into the innovation activity. This particular type of flow acquires fundamental importance in underdeveloped countries, where the scientific and technological system is in its incipient stages and most of the ready-to-use knowledge is imported directly from abroad. Baranson (1969, p. 352) points out that "Most developing countries are now almost entirely dependent upon foreign sources [for their technical knowledge] in India 99 per cent of industrial know-how is purchased under some form of collaboration agreement." These 'collaboration agreement' seldom involve even a minimum of adaptive research.

In Part I it was mentioned that the educational system takes knowledge in all its forms as one of its inputs in order to produce trained manpower. This implies that the scientific and technological system provides basic, potentially-useful and ready-to use knowledge to the educational system. These flows have not been depicted in Figure 2, and they would originate at each of the activities we have described in the S & T system converging to the educational system.

Tables 1, 2, 3 and 4 summarize the characteristics of the main flows of knowledge and the activities that modify and transform them. However, these concepts should be considered as centers of gravity grouping activities that are spread along a continuum rather than sharply divided and self-contained definitions. For example, the distinctions between basic and applied research, and between applied research and development are not as sharp as they are frequently thought to be, and there exist many activities in the scientific and technological system which cannot be properly considered as one or the other.

3. Further Analysis of the Activities Related to the Flow of Knowledge in the S & T System

In view of the difficulties involved in unambiguously classifying activities along this "Research and Development" continuum, additional conceptual schemes have been suggested in the literature. Ackoff (1966), finding that the traditional distinctions of basic research, applied research and development did not mean very much to many R & D managers in industry, proposed a new classification based on the concepts of "offensive research", "defensive research" and "fundamental research".

These concepts proposed by Ackoff provide a very appealing system for classifying research activities. Experience with the use of this taxonomic scheme, has shown that, at least in the case of industrial enterprises, managers do not have much difficulty in classifying their R & D resource allocation in this way, and there is no apparent reason why government and other non-industrial research institutions could not do the same.

According to Ackoff, fundamental (or basic) research is that research which is intended to be consumed by other researchers. He points out that this definition overlaps with the traditional definition of basic research* but is not identical to it, because fundamental research may be intended to be useful and may not be exclusively oriented to providing fuller understanding of the subject matter.

Offensive research is that activity oriented toward generating new products, processes, methods, systems, etc. Its output would be something which is not

---

* For example the National Science Foundation considers that basic research is that in which "... the primary aim of the investigator is a fuller knowledge or understanding of the subject matter under study, rather than a practical application thereof." The OECD and UNESCO consider fundamental or basic research as "... work undertaken primarily for the advancement of scientific knowledge, without a specific, practical application in view."

in existence or in use at the time the research is being done. Perhaps the word "offensive" research does not convey the full meaning of the concept when used outside the industrial context, therefore, we shall prefer to use the term "advance-oriented" research. For example, those research activities oriented toward producting a new and economical source of proteins derived from fishmeal would be considered as advance-oriented research, for the intended product is a new one, not existing at the moment the research is being done.

The concept of defensive research includes all those activities oriented toward improving an existing product, process, method, etc. Its general objective could be considered as reducing the costs of manufacturing a product or offering a service on the one hand, or improving their quality on the other. It follows that the output of defensive research consists of modifications to be effected on something already existing at the moment the research is being done. We also find that the word "defensive" research is rather limited and that it could be replaced by the term "improvement-oriented" research with some advantage. And example would be given by those research activities performed in order to reduce the costs associated with an operating process in some chemical or manufacturing plant.

Ackoff's classification does not distinguish between activities traditionally called 'applied research' and 'development.' By combining his classification with that described above, and interpreting his concepts in terms of a flow of knowledge, we arrive at the diagram of Figure 3. There the activities of applied research, development, screening and identification, and adaptive research have been divided into two groups: advance-oriented and improvement-oriented research. The original flow of potentially-useful knowledge has now been split into two: improvement-oriented potentially-useful knowledge and advancement-oriented potentially-useful knowledge. Similar divisions have been introduced for other flows. Table 5 gives a summary of the new concepts introduced.

The activities and knowledge flows we have considered thus far could be subdivided even further. Research fields, such as social science research, etc. could be introduced into our conceptualization of activities and flows in the scientific and technological system. Similarly, a finer division of these fields would distinguish between the different disciplines involved in each. This approach has been pursued by Gargiulo and Moya (1970) and is entirely compatible with our conceptual model.

4. Analysis of the Non-research Activities that Provide Support to the S & T System

There are a number of activities which can be considered part of the scientific and technological system but which are not involved directly in generating or transforming the flow of knowledge we have described above. These activities may be thought of as creating and providing the conditions, channels or means by which the flow of knowledge, within the system and in and out of it, takes place.

TABLE 1: TYPES OF KNOWLEDGE FLOWS IN THE SCIENTIFIC AND TECHNOLOGICAL SYSTEM

Type of Knowledge Flow	Description	Tangible Flow
Basic Knowledge (also fundamental, pure or scientific knowledge). K_B - internally generated $K_B(i)$ - imported	Knowledge that has wide and indirect applicability. Refers to general phenemena, methods of research, or research fields. Serves as an input to other research activities and does not find direct application without further modification. Takes the form of hypotheses, theories, postulates, formulas, laws, etc.	Formulas, laws, description of methods, theories, principles, etc. in the form of: research papers, research memoranda, books, etc.
Potentially - useful knowledge (also applied knowledge or technological knowledge) K_P - internally generated $K_P(i)$ - imported K_P'- selected from $K_P(i)$	Knowledge that refers to some problem area and has a potential direct applicability, though further development is required before actually making use of it. It can be diffused and communicated to a potential user and serves as an input to the Development activity. Takes the form of description of possible applications, general guidelines for action and decision rules to follow in a potential application, etc.	Techniques, description of possible action and decison rules, etc. in the form of: patents, technological papers and memoranda, description of processes, brochures, etc.
Ready - to - use knowledge (also technological knowlege, or practical knowledge) K_R - internally generated K_R'- internally generated from K_P'	Knowledge that is directed toward a specific application and is ready to be incorporated in the innovative activity. It is the only form of knowledge which is directly utilized through innovation. It takes the form of developed techniques, blueprints, or specific decision rules and actions to follow in a particular application.	Descriptions of specific actions and decision rules to follow in the innovation activity, in the form of blueprints, manuals, specifications, etc.

TABLE 2: ADDITIONAL INFORMATION FLOWS IN THE S & T SYSTEM

Information Flow	Description	Tangible Flow
Problem Area (pa)	A question posed to the S & T System in the form of a description of a problem which presumably can be solved by generating or importing additional knowledge referring a product, method, process, etc. The problem area may also be suggested by the S & T System.	Requests for information, research, etc. in the form of reports, memoranda, letters, papers, feasibility studies, etc.
Specific Request (sr)	A request made to the S & T Sytem in the form of particular conditions under which potentially - useful knowledge will be put in practice through innovation.	Description of specific situation, in the form of reports, memoranda letters, detailed studies of local conditions, etc.

TABLE 3: DESCRIPTION OF THE ACTIVITIES OF THE SCIENTIFIC AND TECHNOLOGICAL SYSTEM WHICH MODIFY THE FLOW OF KNOWLEDGE

Activity	Primary Inputs	Primary Outputs	Characteristics
Basic Research (BR)	1. Basic knowledge (produced internally or imported)	1. Basic knowledge	Generates basic knowledge which feeds primarily into other research activities.
Applied Research (AR)	1. Basic knowledge (produced internally or imported) 2. Problem area 3. Potentially-useful knowledge	1. Potentially-useful knowledge	Generates potentially-useful knowledge which serves as an input to the diffusion activity and needs to be transformed further before being incorporated in the innovative activity.
Development (DEV)	1. Potentially-useful knowledge 2. Specific request 3. Ready-to-use knowledge	1. Ready-to-use knowledge	The ready-to-use knowledge it produces is through diffusion, one of the inputs to the innovative activity.
Diffusion (DIF)	1. Potentially-useful knowledge 2. Ready-to use knowledge	1. Potentially-useful knowledge 2. Ready-to-use knowledge	Its function is to make the potentially-useful and ready-to-use knowledge accessible to its possible users or beneficiaries.
Screening and Identification (S & I)	1. Imported potentially-useful knowledge	1. Potentially-useful knowledge suitable to problem on hand	It reduces the range of potentially-useful knowledge relevant and suitable to the problem area.

TABLE 3 - continued

Activity	Primary Inputs	Primary Outputs	Characteristics
Adaptive Research (AdR)	1. Imported potentially-useful knowledge suitable to problem on hand 2. Specific request 3. Ready-to-use knowledge	1. Ready-to-use Knowledge	It adapts the imported potentially-useful knowledge to the specific problem, producing ready-to-use knowledge which is diffused and used in the innovative activity.
Production Research (PR)	1. Ready-to-use knowledge 2. Information about how it is being utilized	1. Ready-to-use knowledge	It generates additional ready-to-use knowledge based on the way it is being applied.

TABLE 4: SUMMARY OF THE RELATIONS BETWEEN TYPES OF KNOWLEDGE AND ACTIVITIES

Note: The Research Activities can be considered as operators acting on knowledge and information flows.

1. $K_B = BR\ [K_B{}'\ K_B(i)]$

2. $K_P = AR\ [K_B{}'\ K_B(i),\ K_P{}'\ pa]$

3. $K_R = DEV\ [K_P{}'\ K_R{}''\ sr]$

4. $K_P{}' = S\ \&\ I\ [K_P(i)]$

5. $K_R{}' = AdR\ \ [K_P{}''\ K_R{}'\ sr]$

6. $K_P = DIFF\ [K_P]$

7. $K_R = PR\ [K_R]$

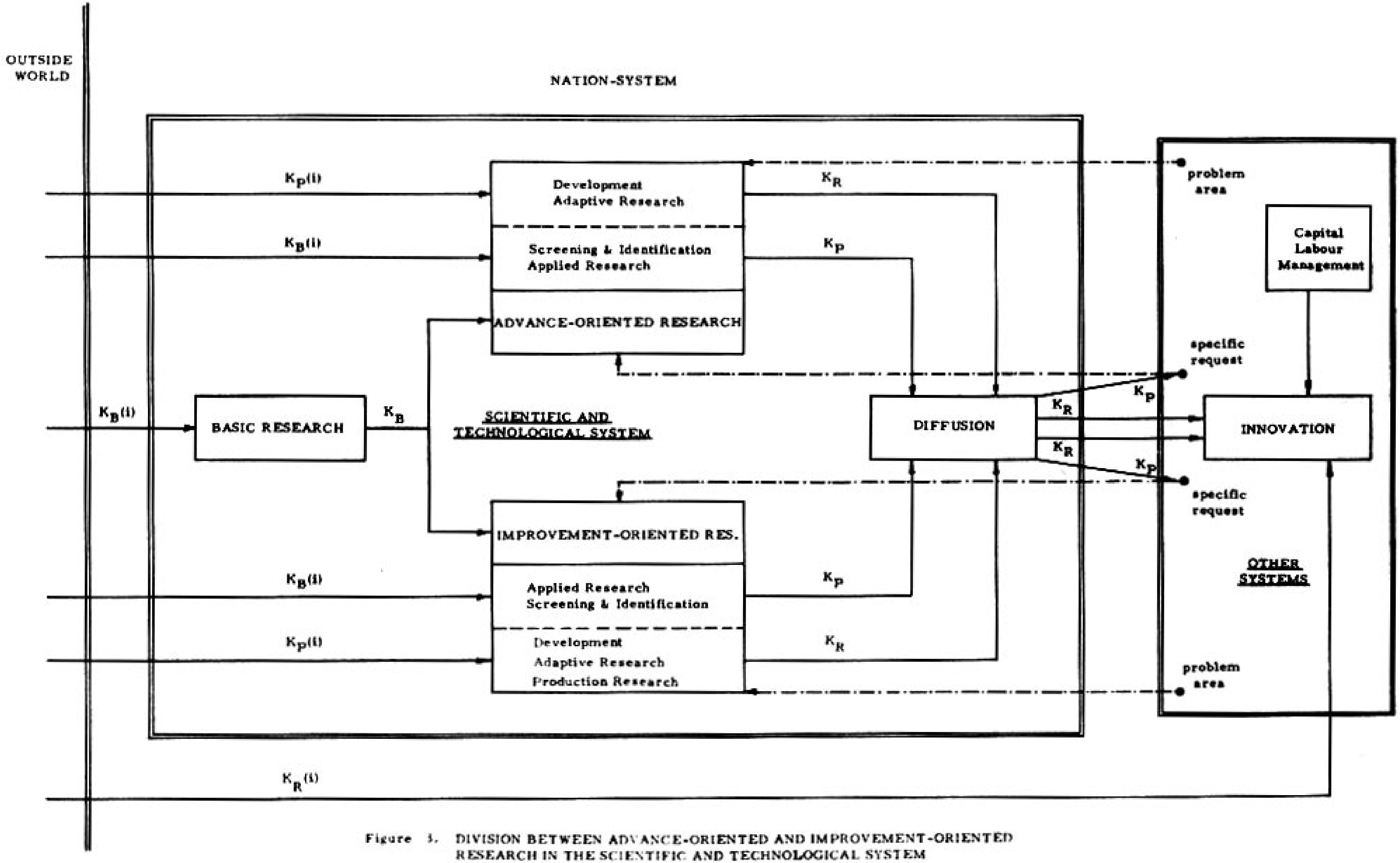


Figure 3. DIVISION BETWEEN ADVANCE-ORIENTED AND IMPROVEMENT-ORIENTED RESEARCH IN THE SCIENTIFIC AND TECHNOLOGICAL SYSTEM

TABLE 5: DEFINITIONS OF BASIC RESEARCH IMPROVEMENT-ORIENTED RESEARCH AND ADVANCE-ORIENTED RESEARCH (AFTER ACKOFF)

Activity	Description	Comments
Basic Research (also fundamental research)	Research activity whose product (basic knowledge) is used as an input to other research activities.	
Advance-oriented research (also offensive research)	Research activity oriented to generate or produce new products, processes, methods systems, etc.	The entity motive or research does not exist at the time of research is being done.
Improvement-oriented research (also defensive research)	Research activity directed toward improving existing products, processes, methods, systems, etc. It could reduce costs or improve quality.	The entity motive of research is in existence at the time the research is being done.

Notes:
1. The activities of applied research, development, screening and identification and adaptive research can belong either to the category of advance-oriented or improvement oriented research. The definitions summarized in Table 3 apply here.
2. The activity of production research belongs only to the category of improvement-oriented research. The definition given in Table 3 applies here, also.
3. The diffusion activity remains unaltered as given in Table 3.

TABLE 6

Non-Research Support Activities in the Scientific and Technological System

	Activities	Function of the Activities
1.	Library services; reference and documentation Center; technology data banks; professional and scientific journals, magazines and books; congresses and conferences; etc.	To provide continuity in the flow of knowledge, both in time and space, by means of knowledge storage and knowledge communication.
2.	Geophysical and geodesical surveys, inventories of natural resources, astronomical and meteorological observatories; national economic accounts; preparation of social indicators, etc.	To provide a background of information and a data base about the nation, which will serve as an input to the scientific and technological system.
3.	Standardization; normalization; quality control; testing and calibrating instruments; licensing and patent granting; design services to users; etc.	To regulate the way the ready-to-use knowledge is put into practice and utilized thereafter.
4.	Museums; zoological and botanical gardens; technical expositions and fairs; etc.	To convey knowledge in all its form to the nation in general and the educational system in particular.
5.	Policy-making and planning for the scientific and technological system.	To regulate the way the S & T System operates and relates to other systems in the nation.

The last group of support activities gathers all those related to the policy-making and planning process for the scientific and technological system. These can be considered as regulating the overall operation of the S & T system by taking inputs from the two regulating systems in the nation, the political and the cultural, and interpreting them in the context of the S & T system. We shall return later to this particular group of support activities and study them in further detail.

5. Institutional and Organization Patterns in the Scientific and Technological System

In the proceding sections we have examined in some detail the activities within the scientific and technological system, indicating also that the groups of activities we suggested could be subdivided even further by specifying fields and disciplines. By following this procedure, we would obtain a set of elementary research and non-research activities within the S & T system. However, these elementary units of activity are not performed independently from each other, quite the contrary, they are usually grouped in some fashion and carried out through some organizational or institutional arrangement. Hence the importance of considering these institutions and organizations explicitly in science and technology policy-making and planning.

This has been emphasized in the literature. Among others, UNESCO (1966), Maheu (1964), Vickers (1969), Rubinstein and Young (1964), King (1969), Friis (1966) and Trist (1969) have dealt explicitly with what UNESCO calls the "operational research network", the web of institutional and organizational arrangements through which the activities in the scientific and technological system are performed. Cornblit (1969) offers an analysis of institutional patterns in Latin American social science research.

Referring to Table 3 it is possible to describe different organizational arrangements grouping the activities considered in the S & T system. A few examples may suffice to illustrate this.

Most large industrial firms (particularly U. S. firms) that carry out research, integrate the activities of basic research, applied research, development, innovation and production research within their own corporate organizations. As an example, Reiss (1969) mentions how all of these research activities are integrated at North American Aviation. Another organizational pattern found in the U. S. is reported by Toulmin (1969b). When analyzing the research-oriented firms along "Route 128" in Massachusetts, he found that their commitment to fixed plant and investment was far less important than their expenditures and commitment to research. This is to say, they concentrate on the activities of basic research, applied research and development, leaving the innovative activity (which incorporates capital, labor and management) to other firms or corporations.

In Latin America, according to the CECIC (1969) background report presented at Viña del Mar, the basic research activities are usually carried out at universities and in a few cases some special institutes, but there is a significant gap with respect to institutions and organizations engaged in the activities of applied research, development, screening and identification and adaptive research. The net result is that the Latin American countries perform a relatively high level of basic research while at the same time import most of their technology in the form of ready-to-use knowledge. Some suggestions have been made with respect to the creation of institutions that would fill in some of these functions (Technological reference centers, technological data banks, specialized research institutes, etc.). Zahlan (1970) found a similar situation prevailing in the Arab Middle East.

In the Soviet Union the activities of basic research have traditionally been carried out at the Academies of Science and their institutes. Applied research and development have traditionally been the function of the institutes associated with ministries and government dependencies in charge of specific economic or social sectors. These two groups of institutions functioned rather independently for a long time with the resulting lack of coordination between basic research on one hand and applied research and development on the other. The creation of "Problem Councils" in 1959, formed by members from the two types of institutes and the consumers of research activities, helped to coordinate the activities and interests of each group. Amann (1970) and Trist (1967) have both provided a description of these institutional changes within the scientific and technological system of the Soviet Union, Trist placing particular emphasis on social sciences research.

From these few examples it is possible to realize that the institutional and organizational arrangements for research activities are multiple and varied. There exist institutions with little or no contact with systems other than the scientific and technological, such as specialized basic research organizations, and institutions that cut across systems, such as universities which operate both within the S & T system and the educational system. Following a similar pattern, industrial corporations with research activities operate both in the S & T and the economic systems.

The multiplicity and variety of possible organizational arrangements creates the need for establishing categories for classifying and describing the institutional patterns found in the scientific and technological system of a given nation. Six dimensions are proposed here to develop these categories; they are based on a consolidation and reinterpretation of earlier work done by Rubinstein and Young (1964), Trist (1970), and Gargiulo and Moya (1970).

We shall call the first dimension Orientation; it refers to the primary function of the institution and is divided into three major types: the academic, the service and the professional orientation. An institution is said to be academically oriented if its primary function is to generate and/or diffuse knowledge, usually through the educational system, without regard to its possible application and implementation. Universities and centers of higher learning generally have this orientation, as well as organizations whose primary objective is the further development of knowledge per se.

The service-oriented institutions are those whose objective is to make available, find possible uses, and/or help to put in practice knowledge that is already available. Diffusion centers, applied research institutes, and consulting firms are among those organizations generally considered as having a service orientation.

The professional is the third orientation found in institutions that gather activities belonging to the S & T system. An organization is considered to have a professional orientation when it combines the activities of providing services and advancing knowledge at the same time. Some applied research institutes and even some consulting firms are found in this category, which is the least numerous of the three.

The difference between the service and professional orientations has been emphasized by Trist (1967) for the case of research in the social sciences, although his observations have wider applicability.

> "There is a great difference between simply acting as a consultant and acting as a researcher in a role where professional as well as scientific responsibility is accepted. In the first case there is no commitment to the advance of scientific knowledge, either on the part of the consultant or on the part of those for whom the inquiry is being made. In the second case this commitment is fundamental and must be explicitly accepted by both sides." (p. 7)

The second dimension refers to the range of activities that the institution is engaged in while performing its function. We shall refer to this as the Scope of the institution. A single-activity institution would be one in which only one activity of those belonging to the S & T system predominates over the others; a dual-activity institution would be one in which two activities of equal prominence shadow all others, and a multi-activity institution would be defined as one that carries out several activities of approximately the same importance and magnitude. This distinction is similar to the multi-purpose and single-purpose classification of Rubinstein and Young (1964).

Before defining the scope of an institution it is necessary to establish a level of detail in whose context the classification is to be made. What may be considered a single-activity institution at one level may become a multi-activity institution if activities are defined in a context involving greater detail.

The third dimension refers to the organizational environment within which the institution operates. We shall call it the Setting of the institution. A first group of categories is given by the three general ways in which an institution can be related to its organizational environment: the institution may be formally independent from other organizations, it may be located within an organization that uses the output it produces, and it may be located in a center of higher learning or university. Consulting firms and independent research institutes operate within the first type of setting, exchanging only resources and knowledge with the organizations in their environment. Research groups belonging to government dependencies or corporations may be considered as operating within the second setting, and university research laboratories typically operate within the third type.

This dimension can be refined further if the economic sectors are taken into account. Gamba (1970) proposes five such sectors that range from government and private enterprises, to mixed enterprises and public and private centers of higher education.

The Source of Funds and the Discipline Mix dimensions are related to the resources utilized by the institutions. The first of these refers to the origin of the financial resources that maintain the institute in operation. The categories of client-supported and non-client-supported organizations are the first to be considered. These could be further subdivided taking into account private or public sources, and so on.

The discipline mix refers to the number of different scientific disciplines in which the members of the institution have been trained and the way they are interrelated. A mono-disciplinary institute would be one in which only one scientific discipline is predominant; for example, a high energy physics research institute or a civil engineering research organization. A multi-disciplinary organization would be one in which several disciplines are present but they work rather independently in different activities or different aspects of a given activity; one example would be given by an aerospace research institute. An inter-disciplinary organization would be one in which scientists trained in different disciplines work together in the same activity or project; many organizations engaged in operations research belong to this category.

The large variety of institutional and organizational patterns suggests the question of whether there is an optimum or "best" mix of institutional patterns for a given nation-system. This is one of the most difficult areas that must be dealt with in a plan for the development of the scientific and technological system. A proper answer would first require the development of a measure of performance for a given institutional mix, and second the development of methods for comparing different institutional arrangements that group the activities belonging to the S & T system.

TABLE 7

The Dimensions for Classifying Institutions in the Scientific and Technological System

Dimension	Categories	Comments
Orientation	Academic Service Professional	Refers to the primary function of the institution.
Scope	Single-activity Dual-activity Multi-activity	Refers to the range of activities of the S & T System that the institution performs.
Setting	Independent Within Center of Higher Learning (Further categories are generated by taking into account economic sectors)	Refers to the type of organizational environment in which the institution operates.
Source of Funds	Client Supported Non-client Supported (Further categories are generated by taking into account economic sectors)	Refers to the origin of financial resources.
Discipline Mix	Mono-disciplinary Multi-disciplinary Inter-disciplinary	Refers to the different disciplines found in the institution and the way they are interrelated.

6. The Flow of Resources to the Scientific and Technological System

We have examined the activities and the institutional arrangements found in the S & T system. In doing so, emphasis was placed on the flows of knowledge and on the ways of grouping the activities that modify these flows. We shall now look at the way resources are transferred from other systems to the scientific and technological system, and how are they allocated to institutions and activities.

In general, institutions and organizations also act as channels through which financial and human resources are allocated to the activities in the scientific and technological system. Conceptually, we may distinguish between allocating resources to activities and allocating them to institutions. For a fixed allocation of resources to a given set of activities, many institutional patterns for channelling them are possible; and if a fixed allocation of resources to institutions is given, it could be distributed among several combinations of activities. Thus we find, in addition to the usual allocation problem of deciding on the level and distribution of resources, the problem of determining the institutional arrangements through which these allocations should be implemented.

Both the economic and the political system (which here includes the executive branches of government) provide financial resources to the S & T system in exchange for the knowledge the latter makes available to them. These resources are given through a variety of arrangements and are channeled to the activities in the S & T system by the institutions that receive them. Some funds are earmarked for specific types of activities and others are given without ties, so that the individual or organization receiving funds may allocate them at its discretion. This flow of funds would also include material resources in the form of equipment, raw materials, etc., for all of these can, in the last analysis, be referred to some monetary unit.

The educational system provides trained human resources to the S & T system, and it is in their allocation that we find some complex problems. First, the required scientists and technicians can be prepared through the educational system of the nation or they can be sent abroad; and also foreign personnel can be used in order to carry out the activities in the S & T system. Thus, we find the need for specifying a strategy for the preparation of trained personnel. Second, problems referring to the optimal number of scientists in each discipline and the time lags required to prepare them also appear at this stage, for some kind of balance between disciplines must be achieved. Finally, scientists and technicians are not like funds or material resources, they have their own will and can usually choose the activities they want to become engaged in; therefore, only indirect methods for inducing them to work in one area or another are available. This is complicated even further by the different ways in which institutions in the S & T system operate and the different types of incentives they offer.

In consequence, when dealing with the processes of allocating human resources, human factors must be taken into account, particularly at the micro level. Gruber and Marquis (1969) and Hodara (1969) provide extensive analyses of the factors affecting the behavior and the productivity of individuals working in research institutions.

However, although these human factors are extremely important for studying the way individual institutions or organizations operate, when we come to analyze the scientific and technological system as a whole, it is not possible to maintain the level of detail that an approach based on the analysis of human factors would involve. When policy-making and planning are done at the level of the S & T system, it is more appropriate to deal with concepts at a higher level of aggregation and abstraction, leaving individual human factors aside.

7. Summary

In this part of the report we have analyzed the scientific and technological system in some detail. The S & T system was conceptualized in terms of a flow of knowledge and the activities that generate and transform it. Three types of knowledge, basic, potentially-useful and ready-to-use knowledge, were identified initially, together with a classification of activities that gathered basic research, applied research, development, screening and identification, adaptive research, diffusion, innovation and innovative research.

One additional classification of research activities, that of Ackoff, was mentioned before proceeding with the analysis of the non-research support activities that belong to the scientific and technological system. The second part ended with an analysis of the institutional arrangements that are possible within the S & T system, and the allocation of resources to it.

PART III: Some Practical Implications of the Systems Approach to Science and Technology Policy-Making and Planning

1. Introduction

In this part of the report we shall trace some of the implications of the systems point of view adopted in parts I and II. In particular, we shall examine its influence on the gathering of information about the S & T system, and on policy-making and planning activities. We shall also mention briefly some of the approaches that other authors have taken with respect to these activities.

2. Implications for Data Gathering

There are three principal reasons for obtaining data and information regarding the scientific and technological system in a given nation. First, information is required in order to make decisions affecting the S & T system with an appropriate empirical basis; second, it is often convenient to make international comparisons of resource allocations, activities, etc. A third reason for collecting data on the scientific and technological system derives from the need for contrasting the theoretical conceptualizations of the S & T system with the realities observed in the field. From this interplay between data and theory a more adequate conceptual model of the scientific and technological system will eventually evolve.

Freeman, in his manual prepared for UNESCO (1969) emphasizes the first two reasons for acquiring data on the S & T system:

> ... Policy makers, particularly those concerned with science planning and management of enterprises, have felt the need for comprehensive information on the availability of, and requirement for human and financial resources devoted to scientific and technological activities in general, and research and experimental development (R and D) in particular. The data are required for cost-benefit efficient programming, planning and budgeting. In addition, science policy makers often feel the need to compare size and structure of their national and technological efforts with those of other countries. (p. 1)

The information needs of policy-makers and planners should constitute the major guide for determining the amount and types of information to gather. This invariably requires having an idea about the way this information will be used for planning purposes, and the types of models that are, or will be, used in making decisions affecting the scientific and technological system. Only a close correspondence between models, hypotheses and planning methods on the one hand, and the data to be gathered, on the other, will lead to improved decision-making and planning. When this correspondence does not exist, planners and policy-makers are usually overwhelmed by a mass of data of which they can make little sense, or face data shortages in critical areas, or maybe both. The net result, in any of these situations, is an expensive and useless data gathering effort.

Therefore, what is required is a continuous interplay between concepts, hypotheses and models on one side, and data on the other. This feedback process provides the basis for a learning procedure which would lead to better models and better data.

It is in this sense that the conceptual models proposed in parts I and II can prove useful for data gathering activities. By taking a systems approach we were able to identify flows and activities in the scientific and technological system which appear to be reasonable and could lead to a variety of planning models. These conceptual models should be refined further after gathering data about the activities we have identified and examining the adequacy of the frame of reference.

However, as long as there are several classifications of activities in the S & T system which have been in use for some time, it is important to point out that our main categories of activities are compatible with those now in use, and that data gathering procedures should be flexible enough to lead to them.

These considerations suggest the concept of "elementary" activity. An elementary activity would be the smallest unit of activity that any survey of the scientific and technological system should take into account. It should lead by aggregation to other groups of categories which are currently in use. If allocations of resources, manpower, etc., are recorded according to these elementary activities they could be aggregated later in whichever way is considered appropriate for model building purposes. For instance, development work in the field of civil engineering, which is method-oriented and which belongs to the category of improvement-oriented research (the development of a new way of preparing concrete with local materials using some existing method in an on-going project would consititute an example) could be considered an elementary activity.

Table 8 provides a summary of the relation between the elementary activities proposed in part II, and it also shows their relation to the categories used by OECD and UNESCO. These refer only to the activities that generate and transform the flow of knowledge, but similar tabulations could be easily prepared for the non-research support activities. Furthermore, as mentioned before, these categories could be divided even further by taking into account scientific and technical fields and disciplines.

TABLE 8

Elementary Activities in the S & T System and
Their Correspondence to Other Definitions

General Categories (*)	Elementary Activities	Correspondence to OECD UNESCO Definitions (**)
1. Basic Research	1. 1 Basic Research	
2. Advance-Oriented Research	2. 1 Applied Research	Fundamental Research
	2. 2 Development	
	2. 3 Screening and Identification	
	2. 4 Adaptive Research	
		Applied Research
3. Improvement-Oriented Research	3. 1 Applied Research	
	3. 2 Development	
	3. 3 Screening and Identification	
	3. 4 Adaptive Research	Development
	3. 5 Production Research	
4. Diffusion	4. 1 Diffusion	(Belongs to the category of related activities)

* See definitions in Tables 3 and 5.

** UNESCO (1969), following OECD (1963), defines activities as follows: Fundamental Research: work undertaken primarily for the advancement of scientific knowledge, without a specific practical application in view.
Applied Research: the same, but with a specific practical aim in view.
Development: the use of the results of fundamental and applied research directed to the introduction of useful materials, devices, products, systems and processes, or the improvement of existing ones.

Similar considerations can be raised with respect to the classification of institutes and organizations; the six dimensions suggested and each of their sets of categories could be compared and related to other taxonomic schemes.

In conclusion, the main implications that can be derived from the point of view taken in this study, are that data gathering activities regarding the scientific and technological system should follow the conceptual model of the system. The model developed in parts I and II is offered as an initial hypothesis concerning the structure of the system and needs to be verified through empirical analysis. Also, the variety of existing classifications and the need for international comparisons suggest the need for establishing a flexible set of categories based on the concept of elementary activities.

3. Implications for Policy-making and Planning

Before examining the implications of the systems point of view on science and technology policy-making and planning, we shall discuss briefly the meaning of these two concepts. UNESCO (1966) and UNESCO/CASTALA (1965) have dealt at length with the concept of "science policy". Halty (1966) has contrasted the meaning, scope and content of science and technology policy with that of science and technology planning.

Science policy refers to those explicit actions by the government that define the guidelines along which the S & T system should operate and evolve. It is essentially national in character and emanates from a political body. Its main function is to establish priorities for evaluating alternative science and technology development plans. In short, science policy is concerned with the definition of the principles and criteria which will be used in evaluating alternative courses of action regarding the scientific and technological system.

UNESCO (1966) suggests that:

> A government's "science policy" might therefore be defined as the sum of the legislative and executive measures taken to increase, organize and use the national scientific and technical potential in order to achieve the country's development aims and enhance its position in the world. (p. 4)

UNESCO/CASTALA (1965) defines a national science policy as:

> ... the art of integrating, organizing and developing the different components of the operational research network in such a way as to attain the general objectives indicated by the country's philosophy in regard to the role of research and of science in the country's development and in determining its place in the world. (p. 222)

These definitions suggest that science policy cannot be defined in absolute terms for all nations at all times, it is heavily dependent on a country's development aims and policies. This has been emphasized by UNESCO (1966):

> It would seem, therefore, that the scope of science policy cannot uniformly be defined for all countries, or even validly defined for an individual country for more than a period of time.
>
> An empirical approach is probably the surest: define the scope of your science policy in relation to the "center of gravity" of the scientific and technical activities necessary to attain the country's development goals. (p. 3)

A list of possible aspects to be considered when defining a national science policy would include the following areas (Halty, 1966)

- A statement of the fields to be covered by scientific endeavor.
- The scientific and technological activities to include.
- The problems to be faced in the S & T system.
- Listing the priorities given to fields, types of research activities, etc.

Therefore, we can infer, for the purposes of our study, that science policy is essentially national in character, that it is a political activity, that it should specify objectives and priorities for the S & T system and that it cannot be defined in a uniform way for all countries or for a country at all times.

Science and technology planning, on the other hand, involves the formulation of specific courses of action to achieve the objectives set for the scientific and technological system according to the priorities and decision rules defined by the national science and technology policy. According to Halty (1966):

> ... scientific and technological planning is the continuous process of formulation and evaluation that takes place within the overall development planning process and in which, through a multidisciplinary effort and the cooperation of all public and private sectors interested:
>
> - short, medium, and long-term goals are established for technical progress;
> - the scientific and technical activities necessary for such progress are organized in systematic form;
> - the human, material and financial resources required are specified. (p. 6)

For our purposes here, science and technology planning will be considered as the collection of activities that transform the general objectives for the scientific and technological system into operational alternatives, courses of action, and resources requirements, using the principles and decision criteria established by the scientific and technological policy.

Within the scientific and technological system, policy-making and planning belong to the last group of support activities that were analyzed in Section 4 of Part II.

Our analysis of the nation as a system emphasized that the scientific and technological system does not stand in isolation and that it is closely related to other systems in the nation, exchanging knowledge, goods and services, human resources, plans and policies and norms with them. We suggested that the function of the political system, one of the two regulators, is to establish policies for the nation as a whole and the S & T system. However, these policies are not defined completely from outside, because there are scientists and professionals who take part in activities within the S & T system and also participate, either directly or in an advisory capacity, in the formulation of scientific and technological policy.

From our analysis we can infer that scientific and technological policy cannot, and should not, be formulated in isolation from other policies in the nation. It must be coordinated and consistent with economic development policies, education policies, human resources policies and so on. At the planning level it is necessary to determine the impact of a scientific and technological development plan on all the systems with which the S & T system is connected. This is to say that the plan for the development of the S & T system should contain an evaluation of its impact on the economic system, the educational system, the policitcal and the cultural systems, as well as the impact on the scientific and technological system itself. Baranson (1969) emphasizes the need for taking into account cultural constraints in the definition of the technological development plan, and also suggests that if the economic system's capacity for absorbing technology is not taken explicitly into account, the plan is quite likely to develop into a collection of lyric statements devoid of realistic evaluations of what is and what is not possible to achieve in the economic system through science and technology.

Therefore, our first conclusions are that policies affecting the S & T system should not be made independent of other development policies, and that the scientific and technological development plan should specify the plan's impact on all the systems the S & T system is related to.

When we examined the scientific and technological system in detail three general levels were identified: the level of activities, the level of institutions and the level of resources. Their interrelations can be outlined by saying that <u>resources</u> are allocated to <u>activities</u> through <u>institutions</u>.

At the first level the scientific and technological development plan should specify the activities to be performed. This refers both to research activities that generate and modify the flow of knowledge and to the support activities that make it possible to materialize the flow. For example, the specification of an appropriate blend of internally generated and imported potentially, useful knowledge would lead to the determination of basic research, applied research and development activities as opposed to screening and identification and adaptive research activities. Also the proper magnitude of the activities under diffusion and the relative priorities of support activities must be all specified in the scientific and technological development plan at this level.

The level of institutions refers to the institutional development aspects of the plan. All the questions about the best mix of institutional patterns that were raised in Section 5 of Part II must be dealt with here. The appropriate division of activities between research organizations and universities, the type of institutions that should do a particular kind of research, and the types of research that a given institution, or groups of institutions, should carry out belong to the class of questions that must be answered here. In short, this aspect of the plan should specify the measures for developing the institutional infrastructure of the scientific and technological system.

The third level has to do with the allocation of resources to and within the S & T system. It is here where the distribution of human financial resources should be specified, taking into account what has been determined at the activities and the institutions levels. With respect to financial resources, the overall allocation of funds to the S & T system, the allocations to activities and to institutions need to be specified. Similarly the plan should contain a description of the types of skills required, the number of scientists, professionals, technicians, etc. that are needed in each field and discipline, relating them to educational development policies and plans.

However, even if a conceptual and operational separation of these three levels is possible, we must dispel the notion that these three levels of scientific and technological planning are independent and that it is possible to proceed in a sequential, linear fashion when determining the activities, the institutional patterns, and the resources to be allocated in the scientific and technological system. These three levels are interdependent, and an independent optimal plan at each level need not lead to the best plan for the three levels taken as a whole. A planning methodology that would simultaneously identify the combination of activities, together with the institutional mix and the allocation of resources that optimize the performance of the scientific and technological system is what planners should aim at. Unfortunately, it is rather unlikely that such a methodology or planning procedure exists, or will ever exist, for we have yet to find an overall performance measure that would take into account these three levels, their effect on the S & T system and on the systems it is connected with, so as to allow optimization, or even recognize an optimal solution once we have it.

A viable alternative may be the development of a planning methodology of iterative character, by means of which a provisional "optimal" combination of activities, a tentative "best" institutional mix based on it, and an "optimal" allocation of resources based on both them would lead to a new revised "optimal" combination of activities, a new "best" institutional mix and so on. An obvious requirement for this procedure is that it should converge to some stable overall "optimal" solution after a finite number of iterations. This suggestion should be taken only as an idea of how it could be possible to develop viable planning methodology.

Some other ideas that are worth exploring in this direction could be derived by analogy with economic development planning. For example, Furtado (1962) proposes that the total amount invested in a developing economy is not as important as the structure of the activities they are allocated to, and the institutional patterns they are channeled through.

Finally, our concluding comments in Part II mentioned that human factors should not be left aside when formulating a plan for the development of the scientific and technological system, although their influence is felt more when planning at the micro level (institute, project, etc.) and relatively less at the level of the whole S & T system with which we are concerned in our analysis. Nevertheless, a plan for the development of the scientific and technological system should consider explicitly measures to improve the environment in which scientists and professionals in the S & T system operate. This involves identifying constraints in the cultural system, taking steps directed toward overcoming them and developing the scientific community, and also developing an atmosphere conducive to creativity in the scientific and technological system.

These are some of the general implications we can derive from our systems point of view with respect to policy-making and planning in the S & T system. We shall return to this topic and define the characteristics of an idealized planning methodology after reviewing some of the approaches to scientific and technological planning taken by other authors.

4. Summary

In this part of the report we have examined some of the practical implications of the systems point of view suggested in Parts I and II. We began by studying the implications with respect to data gathering, showing that the classification scheme we propose and the concept of "elementary activity" are compatible with the classification of research activities that are used by UNESCO and OECD.

Next, we dealt with some implications with respect to science and technology policy-making and planning, reviewing the definitions of these concepts and suggesting a possible iterative planning procedure that would take into account planning at the activities level, at the institutions level and also at the resources level.

PART IV: Review of the Literature on Scientific and Technological Policy-Making and Planning

1. Introduction

In this part we shall give a summary of some points of view and opinions held by other authors. This review is not intended to be a comprehensive survey, it is rather oriented to give an idea of the diversity of opinions and the variety of ideas that have been suggested with respect to scientific and technological policy making and planning. Also, as long as the authors that will be examined here have, for the most part, written extensively on the subject, a thorough evaluation of their work will escape the purposes of the present document.

We shall begin with some of the general suggestions that a handful of authors have made, then proceed to examine the views of an equal number of researchers who have ventured ideas on the topic of science and technology in developing countries, ending with a review of some methods and models that have been suggested for planning science and technology.

2. General Suggestions on Scientific and Technological Policy-Making and Planning

Among the first group of authors we find Libik (1969) who considers that the activities involved in the S & T system are so different in nature that it is not possible to develop a common planning methodology for all of them:

> "It has also become evident that the methods of directing research activity must, in many respects, differ from the methods of economic planning, and furthermore, that the different types of scientific research cannot be planned in a uniform way... basic science can and must be planned, in spite of the fact that the possible outcomes and durations of basic research projects are difficult to estimate...
>
> In the case of applied research, and to an even greater extent in the case of development work, planning is much easier owing to the fact that these activities are concerned with the application of existing scientific knowledge to definite practical targets." (p. 37)

Libik backs his assertions with data from a comparative study of methods for assessing research and development in Eastern and Western Europe. From his ideas we can infer that when developing a science and technology planning methodology it must be kept in mind that the different nature of the activities to which the plan refers may require different planning techniques to be used.

Several authors, Jantsch (1969),Waldo (1969) and Halty (1966) among others, have emphasized the need for taking an "integral" or "total" approach to scientific and technological planning. This implies that planning for the S & T system must be done within the national development planning context. This coincides with the suggestions we advanced earlier when analyzing the implications of the systems approach adapted here. Jantsch (1969, pp. 179ff) suggests that planning for the S & T system should be done within the context of what he calls the "Nature-Man-Society-Technology System", although we fail to see any practical derivation from the analysis he carries out in rather abstract and general terms. Waldo, in a very coherent paper, traces the administrative and organizational implications of several characteristics he identifies as necessary for science and technology planning. He emphasizes the role of external considerations in formulating plans for the S & T system:

> "At one level it would be improper (impolitic and irresponsible) for a public official of a developing country to make decisions regarding science and technology simply on the basis of scientific and technological considerations. At another level it is impossible for him to do so because he will even while trying not to." (p. 401)

Halty (1967 p. 23ff) relates scientific and technological planning to development planning in general and educational and human resources planning in particular, showing their interdependencies and interactions.

In view of the difficulties in formulating plans for the development of the S & T system, particularly due to the lack of reliable and relevant statistics, the lack of substantially agreed theories in the field, and the inherent problems in measuring the output on the S & T system, Ackoff (1968 a) and Waldo (1969) have both proposed to adopt a flexible and experimental approach to scientific and technological planning. According to Waldo (1969 p. 410):

> "In a sense planning -for the development of science and technology- will be unavoidable experimental: and since it must be, a virtue should be made of the necessity. A certain quality and aspect of the scientific method itself should be brought into play: every decision should be regarded as a hypothesis to be tested empirically. All actions taken after planning and as a part of the plan should be regarded as experiments. Observation of the experiments should be continuous and assessment of their 'truth' content. A climate in which error can be recognized, admitted, and corrected without severe penalty must be fostered else error will compound error and waste of resources be escalated. Indeed the national plan as a whole should be regarded as a scientific experiment in the development of science and technology."

Ackoff (1968a, p. 88ff) after suggesting a conceptual model of the scientific and technological system points out that the most effective way of converting the conceptual model into an operational one that would be through the use of experimentation:

> "Science and other subsystems of our nation-system must become the subject of experimental study. Put it another way, the science of science must become an experimental science.
>
> Experiments could be conducted to compare the productivity of different kinds of research establishment and to evaluate various mixes of fundamental and applied research. One could go on this vein indefinitely... If experimental designs are used as a basis for the allocation of national resources to science and technology, feedback can lead to adaptation, and gradually improving policy making can be expected while basic understanding of science, if not the nation is being accumulated." (pp. 89-90)

From the ideas of Waldo and Ackoff, we can infer that science and technology policy and planning could gain a great deal from the incorporation of an experimental attitude and point of view, which would permit to obtain additional information about the best way of planning while the planning process goes on.

Another interesting problem of general character, with which Carter (1969) and Halty (1966) have dealt, refers to the time lags involved in the different types of planning that constitute the overall planning effort of a given country. Carter points out that economic development planning and planning for the S & T system proceed in two different time frames and that the economic system is faster in responding to changes that the scientific and technological one. He argues that the acquisition of scientific manpower, the development of research institutions and the establishment of a tradition oriented toward science and technology take much longer that the implementation of economic development plans.

Perhaps these arguments have articulated best in this passage by Halty (1966 p. 23)

> "... the economic plan can only be normative for the scientific and technological plan in the short run. In the medium and long run, the scientific and technological plan may be normative for the economic in some sectors."

Therefore, we can infer that time lags for the implementation of different development plans should be taken explicitly into account when coordinating them.

The problems of scientific and technological choice have also been extensively dealt with in the literature. Scientific choice refers to the decisions that have to be made with respect to the allocation of basic research efforts to fields and/or projects. Technological choice refers to the decisions regarding the selection of a specific technique that is worth pursuing through the stages of applied research, development and ultimately innovation. Maddox (1969), Rottenberg (1969), Toulmin (1969a), Carter (1969) and most of the papers in the book edited by Shils (1969) deal with the subject of scientific choice, stating criteria to be used in selecting one research project over another. However, the problems of scientific choice are by no means settled, there is much controversy over criteria and even over doctrine in this area of scientific policy and planning.

The problems of technological choice appear, on the surface, to be more tractable than those of technological choice. Eckaus (1962) suggests the classical economic argument that the best technique is that which employs the factor of production available in the nation in proportions most closely related to their availability. Simmons (1969) offers an analysis of prevailing points of view in this subject and Baranson (1969) relates the problem of technical choice to the more general problems of development planning for underdeveloped countries.

It lies beyond the scope of the present report to do a detailed analysis of the problems of scientific and technological choice. This will be done in a later document. However, they are mentioned here in order to emphasize that scientific and technological planning must consider criteria for scientific and technological choices.

3. Some Points of View on Science and Technology in Developing Countries

Among the authors who have dealt with science and technology in developing countries there are four who synthesize particularly well the views held by most authors that have written on this subject. Their ideas may be summarized by saying that underdeveloped countries can reach the level of scientific and technological development of the more developed countries, but only if they make a determined effort to acquire and develop a scientific and technological potential of their own.

De Solla Price (1963) suggests that less developed countries can catch up with developed ones in scientific areas, arguing that the main reason for this lies in the inherent "diminishing returns to scale" characteristic of scientific undertakings: the larger a scientific community becomes, the more difficult it is to maintain its rate of growth and its productivity. Price concludes that:

> "The explosion of science into an underdeveloped country can, then, if serious effort is made, be much faster than one in which science is already established... Thus for the great blocks of the world population we have a sort of automatic handicap race. The later a country starts its determined effort to make a modern science, the faster it can grow. One might therefore suppose that at some time during the next few decades we shall see a rather close finish to a race that has been running for several centuries. The older scientific countries will necessarily come to their mature state of saturation, and the newly scientific population masses of China, India, Africa and others will arrive almost simultaneously at the finishing line." (pp. 101-102)

Waldo (1969) offers a rather cautious approach to the same problem. He rejects the idea that developing countries must follow the steps of more developed ones in their pursuit of high scientific and technological capabilities, but also dispels as illusory the idea that in a few years an underdeveloped country will become affluent through the use of modern science and technology.

> "... It seems incorrect, unjust, even absurd to take the position that countries at a low level of development must progress through successive stages of primitive or crude economic and scientific-technological development in order to become developed... On the other hand, the argument that a developing society low on the economic-scientific scale can in a brief span of years by any means whatsoever become an affluent society of high scientific and technological achievement has an obvious unreality amounting to absurdity, whatever justice or even some kind of necessity may seem to dictate." (pp. 339-400, his italics.)

In contrast with these statements of what is and what is not possible Dedijer (1969) and Ackoff (1968b) give an idea of the magnitude of the task necessary to bring about these possibilities. Dedijer stresses the importance of a cumulative scientific tradition and the development of an adequate scientific and technological infrastructure:

> "... The fruitful pursuit of scientific truth and its application, once discovered, is not just a matter of talented individuals, well trained in foreign universities and supplied with the equipment they desire. These are very important, but the cultivation of science is a collective understanding and success in it depends on an appropriate social structure. This social structure is the scientific community and its specialized institutions. The underdeveloped countries can dispense with it no more than the developed countries can. The advantage of the latter is that they have inherited

it and can develop it as the occasion demands, with the effort which is inherent in traditions which are already well established. The disadvantage of the underdeveloped countries is that they must develop it ab ovo. But develop it they must or they will have no scientific development and no economic and social development either. Until science becomes an autonomously growing institution in the new states, all devolves on policy." (p. 163)

Ackoff (1968b) emphasizes that scientists must make a major commitment toward national development if the goals of development are to be achieved by less developed nations, according to him:

> "Underdeveloped countries, it seems to me, should consider themselves in a state of emergency and, as Great Britain did at the outbreak of World War II, mobilize their best scientists and engineers to work on problems critical to national development, if not survival, with the same sense of urgency that characterized the earlier effort of the British. . .
>
> In brief, what is required now in underdeveloped countries is nothing less than a scientific crusade directed toward national development. . ." (p. 725)

Thus, the general agreement is that underdeveloped countries face both an opportunity and a challenge with respect to the development of their own scientific and technological potential which would, in turn, foster economic and social development for the country as a whole.

4. A Review and Critique of Approaches and Methods Proposed for Scientific and Tecnological Planning

We shall now turn to examine some of the approaches and methods that have been proposed and/or used to assess the relative merits of alternative scientific and technological development plans. Our objective is to survey briefly the spectrum of available instruments for scientific and technological planning and offer a critique of their main features, rather than to provide an exhaustive analysis of the subject. It is hoped that this review will familiarize the reader with the approaches and methods that have been developed and give him an idea of their possibilities and limitations.

A survey of the literature identified about a dozen methods for scientific and technological planning. Some of these involve fairly sophisticated models and data gathering efforts while others make use of intuitive rules and common sense.

Furthermore, some of the methods we shall review have been developed with the explicit aim of providing a tool for scientific and technological planning, while others have been developed for descriptive or explanatory purposes, but may be employed as a planning tool. These methods are not necessarily exclusive and it is likely that a comprehensive science and technology planning instrument will include two or more of the methods described below as components.

Two broad categories have been identified for the purposes of our analysis. The quantitative and the non-quantitative approaches. The difference between them is primarily a matter of degree and the methods have been classified as belonging to the first or second approach on the basis of whether they emphasize quantitative or non-quantitative aspects, rather than whether they deal only with one or the other.

We have excluded from our analysis those methods and models that deal with research project selection at the micro-level. While they are very important in research programming, they escape the purposes of our analysis here, which is oriented toward the broader questions of national planning efforts in the area of science and technology.

Quantitative Approach

The methods that can be classified within the quantitative approach seek to establish direct quantitative relationships between expenditures in scientific and technological activities and the economic benefits that might be obtained from them. By establishing such relationships and developing a measure of performance based on them, it becomes possible to evaluate which of alternative plans for the development of the scientific and technological system should be preferred.

Cost/benefit and input/output analysis belong to this category, as well as the "econometric" methods considered here: the regression, the disaggregation and the production functions methods. Under the heading of "Other Econometric Approaches" we examine briefly the approach followed by Professor Mansfield.

When describing the methods below, no efforts have been made to distinguish between the macro-economic, the sectorial and the micro-economic method of analysis. If it is apparent that a particular method is better suited for one or another level of analysis it has been mentioned when describing it.

A variety of ad-hoc quantitative methods have been used in the past for evaluating the impact of research and development expenditures on some segments of the economy of a nation. In addition to the methods or "schools of thought" to be mentioned, there is the whole area of mathematical models that are constructed by using traditional operations research techniques, and whose purpose is to help in the management of research and development programs.

Most of these models and methods refer to decisions at the project level, and are concerned with the estimation of returns from particular research projects, with the selection of "optimal" research portfolios, with the determination of "best" stopping rules for funding R & D projects, and so on. Very little has been done at the level of the Scientitic and Technological system using these models. Because they are not readily generalizable they are not dealt with in detail here.

Cost/Benefit Analysis

In a wide sense, cost/benefit analysis comprises all methodologies that attempt to evaluate quantitatively the relative advantages of alternative plans of the development of the scientific and technological system. This is so because, in some way or other, all of these quantitative must compare the total expenditures of resources required for a given plan with the benefits they might accrue to the nation. Therefore, some of the comments that have been made regarding the use of cost/benefit analysis may be generalized to all quantitative approaches. For example, the United Nations Advisory Committee on the Application of Science and Technology (1966) warns that:

> ". . . There are, however, great difficulties in the way of solving most practical problems of choice through the application of . . . . quantitative techniques, and many pitfalls will beset an unwary user of them. One obvious difficulty is the impossibility of evaluating intangible benefits in monetary terms, such as health or human life itself. A second difficulty has to do with uncertainty over the rate of discount to use in calculating the present value of future benefits. This is part of the problem of whether to evaluate in terms of market prices or in terms of so-called shadow prices, or accounting prices-theoretical prices chosen to correspond as closely as possible to "true" national scarcities. This list of major difficulties could be considerably extended." (p. 103).

The cost/benefit approach has been used extensively in the selection of individual research projects, but relatively little in preparation of overall science and technology development plans. Foster (1968) provides a summary of applications of this method, dividing them into micro-economic and macro-economic. His category of macro-economic studies includes most of the cost/benefit studies done with planning purposes in mind.

Pigganiol et. al. (1967) provide a concise definition of cost/benefit methods as they are generally understood in the more strict sense:

> "Cost/benefit analysis consists in evaluating from the start, the costs and benefits of research projects, as well as the costs, benefits and

technical period of application (innovation and its propagation) in the event of their completion, in order to appraise the profitability of research-innovation-propagation chains, each in relation to others... " (p. 71, their emphasis)

There are three steps in the preparation of cost/benefit studies: (a) the evaluation, in some convenient quantitative unit, of the total benefits of the project, program or plan; (b) the calculation of total expenditures in resources, or costs, involved in it, and (c) the computation of the cost/benefit ratio, which might be expressed as a simple ratio of total costs to benefits, or expressed in terms of annual profitability rates, or similar measures based on the calculations of steps (a) and (b). This procedure repeated for alternative plans or groups of research projects would order them according to their relative merits.

Cost/benefit methods in the evaluation of research plans have been criticized for a variety of reasons, which range from their failure to incorporate considerations regarding the inherent uncertainty of research plans and the possibility of obtaining partial success in research efforts, to the difficulties in comparing cost/benefit ratios for research activities that refer to different objectives or functions. Janisch (1969) has made some relevant comments on this last aspect:

> "What is badly missing, is a generalized cost/effectiveness approach in two stages: the first stage would permit us to compare the outcomes of specific technologies within a functional system (such as "urban transportation", where a particularly great variety of non-linear changes in the form of new technologies ought to be introduced into the horizontally integrated planning of this function). The second stage would then allow us to compare the effectiveness of plans for entire functions in relation to plans for other functions - in short, aid the effective integration of functions in the framework of anticipations. This second stage may still be relatively far off. But we can hope to develop the first stage within the next few years, if we recognize its importance. " (p. 196)

Therefore, it appears that cost/benefit analysis (understood in the strict sense) has, at the present stage, a limited application in evaluating plans for the scientific and technological system. This is a consequence of the difficulties that arise in the evaluation of the total benefits of a given plan, the many uncertainties and indirect payoffs that are usually associated with research efforts, and the problems involved in preparing aggregate cost/benefit ratios for alternative plans, each of which include a variety of individual research programs and projects.

Input/Output Analysis

The use of input/output analysis to determine the best allocation of resources to scientific and technological activities is a possibility that has been considered by many authors. The application of this method presupposes the existence of a fairly sophisticated national economic accounts system that would permit to construct a reliable and accurate input-output matrix of the economy. Furthermore, an implicit assumption involved in the use of this method, is that only economic gains that are reflected in such an accounting system will be taken into consideration when deciding on alternative plans for the development of the S & T system.

Thus, this approach not only does not consider the impact of alternative research plans on systems other than the economic, but even within the economic system it has a bias toward plans that reflect their impact on the input/output system of accounts.

Perhaps the one of the best science and technology planning methods based on input/output analysis is that developed by Johnson and Striner (1960). They suggest rearranging the traditional input/output matrix, grouping the most important sectors of the economy in one part of the total matrix area, and then, taking these sectors as a basis, allocating research funds among them in such a way that the total multiplier effect in the economy would be greatest. They realize that this method does not take into account the allocation of basic or undirected research (they call it "seed research") and suggest that a complementary evaluation should be made in order to allocate funds to this type of research.

Their method also calls for the development of a "research funds flow" matrix and the addition of an extra "research industry" sector to the traditional input/output matrix format. They summarize their procedure as follows:

> "First, construct a matrix relating each (economic) sector to each other sector, with a research industry sector now included in our concept of an input/output matrix.
>
> Second, using different final demand levels, by means of dynamic linear programming establish the feasibility of the inverse matrix implications of each final demand program. Choose the final demand program that seems most practicable. Use this final demand 'mix' to establish the 'n year' program level.
>
> Third, rearrange the n year matrix as a triangular matrix.
>
> Fourth, allocate R & D expenditures on the basis of an 'Iterative Productivity Gain Index (IPG Index)', thus allocating funds on a productivity gains proportion basis.

Fifth, by means of D-R-D (Donor-Receiver-Doer) research accounts, develop an R & D flow program that concentrates the R & D in such a manner to benefit the higher IPG Index sectors." (pp. 26-27)

The Johnson and Striner input/output method for planning research activities appears, on the surface, to be an efficient approach for determining the economic impact of research plans. However, it also requires the development of research accounting procedures which impose data requirements that are even beyond what most developed countries have been keeping record of. Therefore, before this particular method is applied, substantial efforts are required in order to develop adequate data both on economic and R & D accounting.

Piganiol et. al. (1967) have also commented on the application of input/output method of planning research activities. They stress the static nature of the technical coefficients of the input/output matrix, and suggest that a dynamic treatment of them would be necessary if the impact of technological changes induced by research efforts were to be reflected.

> "The use of these (input/output) tables in economic forecasting would necessitate their dynamic treatment, that is, forecasting future technological coefficients or the evolution of current technological coefficients under the impulse of technical progress. The 'dynamization' of coefficients assumes we know the nature of technological innovations (including growth elements of productivity) capable of inclusion in the national production system through the advance of science and technology and readily acceptable to the various sectors of the economy." (p. 3)

In addition to the problems of obtaining a set of dynamic technological coefficients for the input/output matrix, there are problems caused by the aggregate nature of these coefficients. As long as a manageable table must include only a limited number of economic sectors, a certain degree of aggregation becomes necessary in recording the inter-industry transactions. However, if there is a wide difference in the technical level of individual firms within a given sector of the matrix, the use of input/output methods for scientific and technological planning may prove to be grossly inaccurate. For example, in many underdeveloped countries we find the phenomenon known by the name of "technological dualism" which refers to the simultaneous existence, within one economic sector, of a group of firms with a high technological and another groups of firms at a rather low level of technology. Clearly, the use of an aggregate coefficient for the sector as a whole, even if it were treated in a dynamic way, would not give an accurate picture of the impact of research programs on the productivity of that sector.

Correlation Analysis

The first work relating research expenditures and growth by means of correlation and regression analysis appears to be that of Ewell (1955, reported in Williams, 1969), who sought to establish correlations between expenditures in research and development during the period 1928-1953, and the growth of industry and the Gross National Product during the same period. On the basis of these regression equation, using the year 1954 as a basis, he projected the growth the GNP would experience in the U. S. if certain levels of research expenditures were achieved. As it turned out, his estimates were considerably exceeded by actual development, due mainly to the fact that he was extrapolating a relatively slow trend in research expenditures which was considerably accelerated in later years.

Another study along similar lines was performed by Minasian (1962), who used a sample of 18 U. S. chemical firms to test the general hypothesis that "The greater the research and development expenditures, . . . the greater is the subsequent rate of growth in the productivity of a firm". Minasian was very careful to state the extent to which results are generalizable, and mentioned that his sample was strictly a nonrandom one. Therefore, the results apply only to those firms that were studied and cannot be generalized at the sector or macroeconomic level. His analysis of the correlation coefficients and their significance led him to the conclusion that:

> ". . . The relevant research and development expenditure was found to be a highly significant independent variable explaining not only the rate of growth in productivity but also the trend of the profitability of the eighteen firms in the sample.
>
> I hope of shedding some light on the chain of causality involved, we tested alternative hypotheses that increases in productivity might be explained by profitability or investment. Both hypothesis were rejected. . ." (p. 140)

However, Williams (1969) pointed out that similar studies in England failed to show the types of correlation found by Minasian and also took exception of the conclusions he arrived at:

> ". . . the main problem is one of interpretation. Should we conclude, or imply, that if the low growth industries had spent more on research and development they would have grown faster? The issue is not simply whether more physical output could have been produced but whether more output could have been profitably produced." (p. 95)

Other correlation and regression type of studies have been performed by Johnson and Striner (1960), Szakasits (1962, reported in Szakasits 1968) and Dedijer (1962). In all these cases the authors sought to establish regression equations relating GNP per capita or a similar variable with expenditures in research and development. For example, one of Johnson and Striner's equations was of the form:

$$P_c = 1,200 \quad R^{2/3}$$

where P_c is per capita national income in 1952 in U. S. dollars and R is the percentage of the GNP spent in research and development. The equations developed by Dedijer and Szakasits follow a similar pattern.

Another study made use of regression methods was carried out by Spencer and Woroniak (1967) on the Japanese economy. Their objective was to develop quantitative relationships which would help to explain the economic effects of technology transferred from other countries, as well as the effects of their own in-house research efforts.

Spencer and Woroniak stated the objectives of their study in the following terms:

> ". . . Its purpose is to determine the feasibility of and the problems involved in analyzing the impact of new technology on the domestic and foreign economy of Japan in this period (1950-63) (impact functions). At the same time an attempt is made to determine the capacity of an economy to absorb an advanced technology (absorption function) by estimating the relationship between some discernible proxy representing the intake of new technology and the socio-economic factors which have been selected as explanatory variable on the basis of logical theoretical considerations. . ." (p. 411)

They identified 18 possible independent variables on the basis of results from current economic theory and developed three types of multiple regression equations. The first of these had the amount of export sales related to new technologies as dependent variable. The second had the total domestic sales related to new technology as the dependent variable. These two dependent variables were regarded as functions of seven and nine independent variables respectively. Also, these two variables, exports and domestic sales, were considered as indicators of the impact the new technology acquired had on the Japanese economy during the period they studied. Their third multiple regression equation used a proxy independent variable, the total payments to the foreign suppliers of technology, as an indicator of the capacity for absorbing new technology.

When the coefficients of the multiple regression equations were calculated, Spencer and Woroniak found that in the first two cases the number of significant independent variables was reduced to three. These reduced equations yielded estimates that were very close to actual statistical figures. In both cases the multiple correlation coefficient (R^2) was above 0.99. In the case of the third equation, which started with nine variables, only one of them was deleted, leaving the final equation with the total payments for borrowed technology as a function of eight independent variables. Once again the multiple correlation coefficient was above 0.99.

The "impact" functions or equations that they arrived at can be expressed in the form

$$EJ = f\ (EW,\ MT_{mch-1},\ RD)$$

$$SD = f\ (I/L,\ MT_{rm},\ RD)$$

where

EJ, Japanese Exports related to new technology
SD, Domestic sales related to new technology
EW, World Exports
RD, Total research and development expenditures
I/L, Gross domestic investment divided by total employment
MT_{rm}, Imports of raw material related to new technology
MT_{mch-1}, Imports of machineries and producer's goods related to new technology (preceeding year)

with these results, Spencer and Woroniak concluded that:

> "In effect, the impact regressions seems to indicate that the growth of output of manufactured goods connected with advanced technology is closely related, on the one side, with the nations's own planned, predetermined allocation of resources to raise its technical niveau. The other significant input seems to be the import of technically advanced raw materials and machinery as an identifiable measure of borrowed technology." (pp. 453-454).

With respect to the absorption function (third equation) they arrive at the conclusion that:

> "Results from the absorption regression point out that the absorptive capacity-as illustrated in the case of Japan-would seem to depend

> mainly on the complex of variables representing the educational and technological levels, the totality of effort in science and research, foreign contacts, and intelligent action of the Government such as stimulating technical borrowing by well planned depreciation levels. As expected the regression equation retains also such common economic variables as national income and foreign exchange reserves. (p. 454).

These results are hardly surprising. However, they indicate by means of quantitative analyses that both the impact of new technology on the economy of a country and the capacity for absorbing it are dependent on a combination of factors and actions which include, not only expenditures in research and development, but also coordinated investment programs, adequate policies for importing raw materials and equipment that incorporate new technology, etc. Spencer and Woroniak also draw the conclusion that ". . . the transfer of technology is governed by a complex of factors which create a setting or an institutional milieu conducive to the transfer mechanism and its impact. . . " (p. 456)

If the study of Spencer and Woroniak constitutes an example of what is possible to obtain from correlation and regression analysis with a rather sophisticated approach, it also constitutes an example of the limitations of these methods. Once the initial group of variables has been screened and the range of relevant variables reduced to a few by examining multiple correlation coefficients, there is very little that regression methods add to the understanding of the interrelations between these relevant variables, including the dependent one.

These methods have been criticized in the past for this and other reasons. Ackoff (1968a) is particularly skeptic about their use as a planning tool:

> "... (one) orientation which tends to dominate much of the current planning efforts is devoted to finding out how inputs and outputs have been associated in the past. Such associations are generally sought by means of regression analysis. However, no matter how much statistical sophistication is employed in such analyses, they cannot provide more than descriptions of past relationships. If one adds to such descriptions the assumption that the system which transforms inputs into outputs will remain stable in the future they can be used as a basis for prediction, by extrapolation. Such descriptions and extrapolations explain nothing. . . .
>
> Hence, whatever else they may yield, they cannot yield understanding. . . . Regression equation no matter how much they

are obscured by complex econometric manipulations provide us with no basis for designing proposed structural changes, and they do not even provide a basis for evaluating proposed structural changes once they are formulated. (pp. 84-85).

"Regression analysis can be useful as a filter, to select combinations of variables, relationships between which should be sought by experimental methods. . ." (p. 89).

Some other efforts have been made to relate expenditures on research and development at the level of industrial sectors. Duckworth (1967), for example when describing what he calls the "comparative" approach to the allocation of resources to R & D, makes comparisons between expenditures in research and development and subsequent rate of growth for several industries in the United States and the U. K. These comparisons are based on a correlation analysis of the R & D expenditures and growth for different industrial sectors.

Disaggregation Methods

This method of analysis has been developed by Edward Denison (1962, 1967a) and consists in isolating the individual components that contribute to the total growth rate of national income for a given country. Denison began studying the U. S. economy and later extended his analysis to include European countries.

In following this method the contribution of technological advances to the growth of the economy is found by subtraction. Once the contribution of changes in inputs is accounted for, then the relative contribution of changes in output per unit of input is determined; part of these changes in output are then explained in terms of the contribution of technical knowledge. This is the reason why the contribution of technology to economic growth is considered as a "residual factor", obtained by difference once other factors are taken into account.

Denison (1967b) describes methodology as follows:

"My method of analyzing growth distinguished broadly between the contribution of changes in inputs and the contribution of changes in output per unit of input. To measure the contribution of labour, capital, and the land of change in each of these inputs, subdivided as necessary and possible among components, must first be measured. The growth rate of each input is then multiplied by its share of national income to obtain its contribution to the growth rate of national income. The contribution of all inputs together is the growth rate of total factor input when the separate inputs are combined by use of income share weights. The contribution of output per unit input is the amount of the growth rate that is not explained by the growth of inputs. To divide the contribution of output per unit of input among its sources required a separate technique for each source. Broadly speaking, I have tried to isolate the contributions made by important changes in resource allocation, by economies of scale. . . A couple of adjustments were also made for difference in deflation techniques. I was left with a residual representing the contribution of advances in knowledge, and catching-up of technique, the contribution of all changes not explicitly measured such as how hard people work, and, of course, noncompensating errors in the growth rates themselves and in the estimates for the sources dealt with explicitly." (pp. 1-2, emphasis ours).

This is the particular methodology followed by Denison in his study Why Growth Rates Differ (1967a) in which he compared the rates of growth of nine European countries and the U. S. However, his method of analysis is far more sophisticated than it appears by examining the quotation above: he takes into account changes in the number of working hours, changes in weather conditions in so far as they affect crops, changes in the composition of the labour force, changes in the educational levels of the labour force, changes in the stock of capital, etc.

In this way he estimated that the contribution of increased knowledge and its application accounted for 20 per cent of the growth rate of the Total Real National Product in the U. S. during the years 1929-1957. The growth of inputs accounted for 72 per cent of this growth, and the growth of output per unit of input from sources other than increased knowledge and its application accounted for 12 per cent. (1962, Chapter 21).

From his analysis Denison derives a series of alternatives for increasing the rate of growth of the economy. Some of these conclusions were examined in the OECD report The Residual Factor and Economic Growth (1964).

However, disaggregation methods of the type used by Denison do not provide much help in planning activities for the scientific and technological system. Indeed, they were not developed with that aim in mind and the residual character with which technology is treated does not provide a basis to decide on the allocation of resources to the scientific and technological system. All that can be said, as in the case of regression methods, is that if past trends continue the contribution of increased knowledge and its application would be a certain order of magnitude.

Production Function Methods

Production function methods have been widely used in economic theory for describing and explaining economic behavior at the firm level, and by the use of aggregate production functions, at the sector and national levels. However, it is only recently that economists have turned their attention to examine the effects of technological change on their interpretations of economic behavior, and this has led to modifications of the traditional production functions (which included explicitly only capital and labour factors) in order to incorporate explicitly the effects of technological change.

Brown (1966) provides a summary and review of the different approaches to the measurement of technical change and the impact of technology that are based on the production function concept. Theoretical treatments of the subject generally refer to the mathematical form of the production function and its properties, while empirical analysis almost invariably require logarithmic transformation of these functions to linearize them and the use of regression analysis to fit the linear functions to statistical data.

Two main types of production functions have been used for the purpose of analyzing the impact of technological change: the Cobb-Douglas and the Constant Elasticity of Substitution (CES) production functions, although the first can be considered as a special case of the second.

The basic form of the Cobb-Douglas production function is:

$$X = AN^{\alpha}C^{\beta}$$

where X is output, N is a measure of labour services and C is a measure of capital services. A, α, and are parameters to be determined empirically. The effects of technological changes are reflected on the value of these parameters. For example, variations in A indicate changes in the efficiency of the production process the function represents, the sum of $\alpha + \beta$ indicates the degree of returns to scale, and variations in the ratio of α to β indicate various types of technological changes. Brown (1966, pp. 35-41) provides a detailed analysis of these changes. This type of production function has been used, in some cases with various modifications, by Brown (1966), Solow (1959) and earlier by Tinbergen (cited in Brown 1966, p. 110).

The Constant Elasticity of Substitution (CES) type of production function has the general form

$$X = \gamma[kC^{-\alpha} + (1-k)N^{-\alpha}]^{-v/\alpha}$$

where X, C, and N have the same meaning as in the Cobb-Douglas production function and γ, k, α, and v are the four parameters of the equation. γ is a scale parameter denoting the efficiency of a technology, k indicates the degree to which the technology is capital intensive and is defined in the interval $0<k<1$, v represents the degree of homogeneity of the function or the degree of returns to scale, and α is defined from the relation

$$\sigma = \frac{1}{1+\alpha}$$

where σ is the elasticity of substitution of labour for capital. This particular class of production functions was derived independently by Arrow et. al. (1961) and by Brown and de Cani (1963), and it has been widely applied to estimate the effects of technological change on the growth output. Recently Katz (1968) used CES production functions to examine the growth of the Argentine economy and the relative importance of technological change.

Another attempt to deal with the impact of technological change on economic progress through the use of production functions is that of Nordhaus (1969). He separates explicitly the effect of technological change in his formulation of the production function, which is of the form

$$X = a(R)F(K, L)$$

where X is output, a(R) represents the level of technology and is called the "invention possibility" function. F(K, L) is a conventional production function of the types discussed above. From this initial formulation he proceeds to determine the optimal level of research for a firm, introduces modifications to take into account imperfections in the invention market and analyzes the economics of patent systems. He also gives a treatment of technological change that takes into account growth in the economy. However, the major shortcoming of Nordhaus' work is that no empirical basis are provided for his analysis and his treatment remains only theoretical.

The use of production functions to determine the best allocation of resources to research activities would appear to be a natural extension of the uses these functions have been put to. If a set of production functions could be developed at the industry or sector level, then it would be possible to estimate the economic effect of different types of technological changes induced by research and development activities. However, it appears that production functions have not been used for this purpose, and that there are many difficulties in doing so.

The criticisms that were made with regard to the use of regression methods are to some extent valid also for the use of production functions because their parameters must be estimated by regression analysis. Piganiol et. al. (1967) consider that production functions would not be very useful for determining the allocation of resources to the scientific and technological system:

> "It has to be realized that production functions of the Cobb-Douglas type are distinguished by certain features, which impose a strict limit to their possible contribution to research programming. They are "ex-post"

and global, and consequently threat technological progress as an autonomous datum. They seek, in fact, to account for how technological progress has in the past been integrated to the national production system. The effect of technological progress on growth is measured in global and "residual" terms in relation to the effect of other production factors such as capital and labour." (p. 4, their emphasis).

It appears that some of the shortcomings mentioned by Piganiol et. al. have been overcome by the work of Nordhaus but only at the theoretical level.

Other Econometric Methods

Among the authors who have used mathematical models and econometric techniques Mansfield (1968) is especially worth reviewing. Over a period of several years, Mansfield has developed a group of mathematical models which appear to predict and explain the research and development behavior of firms, groups of firms, and industrial sectors.

As an example of the types of models suggested by Mansfield, we have the following simple model used to predict the level of a firm's research and development expenditures: (1968, pp. 22ff)

$$r_i(t) = R_i(t-1) + \theta_i(t)\ [\bar{R}_i(t) - R_i\ (t-1)]$$

where $r_i(t)$ is the ith firm R &D budget for year t, $\bar{R}_i(t)$ is the desired expenditure for the year t and $R_i(t-1)$ is the actual expenditure for year (t-1). $\theta_i(t)$ is the fraction of the way the ith firm moves toward the desired expenditure. Mansfield develops this sample model to include consideration regarding the values and meaning of $\theta_i(t)$ and $\bar{R}_i(t)$. It was found to be a very good predictor of the research and development expenditures in several chemical and petroleum firms.

Mansfield has also developed models that predict, and to a certain degree, explain, the research and development behavior of firms and industries in terms of expected returns form research, size of firm, and market structure. His studies of the rate of diffusion of innovations, or the "rate of imitation", among firms in an industrial sector, also make use of mathematical models which are not based on the concept of production functions. Mansfield also tackled the difficult problem of determining one marginal return of investment in research and development. Using the framework of production function and many simplifying assumptions, he was able to determine the order of magnitude of the normal returns to expenditures in R & D for particular industries in the U. S.

It is rather difficult to make generalizations on the basis of models of this type. Mansfield is cautious with respect to generalizing results from his models, which deal with R & D behavior only at the firm and industry levels. Although there are many implications to be derived with respect to policy making for the S & T system from these types of models, very little can be extracted from them in order to decide on alternative plans for the development of the scientific and technological system. Perhaps the major contribution of this type of studies is to suggest a methodology based on the use of mathematical model constructed especially with the purpose of planning for the scientific and technological system.

Non-Quantitative Approach

The methods classified under the non-quantitative approach differ from those analyzed in the preceeding section in that they do not seek to establish a quantitative relationship between growth in output and expenditures in scientific and technological activities, but rather to propose decisions rules and suggest courses of action with regard to planning activities based on logical, and sometimes intuitive, grounds.

Some of them, for example, the "requirements and possibilities" methods, and the "revelance tree" method, suggest general frameworks for encompassing a large number of activities involved in scientific and technological planning. Others, like the "heuristic methods", offer specific rules for action.

We shall now examine those methods that can be classified under the non-quantitative approach.

The Requirements and Possibilities Method

The general philosophy of this method is based on the premise that it is possible to separate the "requirements" for scientific and technological activities from the "possibilities" for carrying them out, evaluate each independently and, by synthesis, to prepare a plan for the development of science and technology. The "requirements", or "social demands", are extracted from the general economic and social development plans and from detailed sectorial analyses of the economy. The "possibilities" for doing research and development work, as well as other related scientific and technological activities, are derived from an inventory of scientific activities and a diagnosis of scientific and technological potential in the nation.

This approach has seen advocated by OECD (1968), Chesnais (1970), the Department of Scientific Affairs of the Pan American Union (1968) and Halty (1966). The method proposed by OECD (1968) and extended by Chesnais (1970), calls for a two level analysis in order to determine the requirements of science and technology: (a) a preliminary analysis of the overall development strategy to identify important sections of the economy, and (b) a detailed sectorial analysis to derive the specific requirements for science and technology. With this information on hand, general recommendations are made and a programme of expenditures in science and technology is prepared.

The stages involved in the sector analysis is the OECD method for determining requirements are stated below (OECD, 1968).

(i) a purely economic analysis consisting of a study of the sector's place in the economy as a whole and of its prospects of future development (based wherever possible on the statistical forecasts of the Plan or of other official documents). This section of the analysis must aim to determine the potential economic significance of developing the corresponding research activities and to assess the urgency of doing so;

(ii) an economic and technical analysis studying the main features of production, size of production units, techniques and methods generally used, etc.) in order to detect the sector's main technical economic problem and the causes of any inefficiency or backwardness, etc. The purpose of this study is to classify these various problems in order to determine which of them need science. For what must be done here is to define as accurately as possible which of the sector's problems call specifically for solutions of a type which can only be provided by research activity. It is also important to pick out the problems which seem to relate to technical education or better dissemination of knowledge, taking care always to distinguish them clearly from those related to research or development activity proper. Indeed the study may well reach the conclusion that it is not so much research activity which is deficient, as these related activities of education and dissemination. There would be nothing surprising in that, but it should be clearly explained and reasons given;

(iii) a detailed analysis of the present state of research in the fields corresponding to the sector studied. Here we shall consider the amount of research, but also and above all its present structure (number and size of research centres, location, personnel qualifications, state of premises and equipment, etc.) and its present orientation (number and nature of research projects, etc.). The purpose of the study is to determine to what extent the present amount, structure, and orientation of research is capable of answerering now, or is in a position to answer in the future the needs of research as previously defined. This section of the analysis is essential if we wish to make specific recommendations regarding the future development of research and development activities and if we propose to determine with some accuracy in what fields and to what amount it seems necessary to invest in equipment or to recruit scientific personnel. This section should also comprise the elements of a constructive critical assessment of the research work now being done;

(iv) the last stage of the analysis consists in synthesizing the results obtained, in such a way as to:

(a) make general recommendations on the role which research and related activities can play in the development of the sector and consider what measures should be taken to this, and

(b) prepare a detailed programme of the expenditure of resources -- manpower, equipment and cash -- which seems necessary. It should be noted that this programme should ideally include a breakdown of expenditure year by year. (p. 118)

In order to determine the possibilities for doing the required scientific and technological activities, the OECD method involves a detailed inventory or research activities and a diagnosis of their possibilities for future development.

The Department of Scientific Affairs of the Pan American Union (1968) proposes a similar method, which has also been articulated in detail by Halty (1966). The four main components of their methodology are (Department of Scientific Affairs, PAU, 1968 p. 27).

1. Analysis of the present technological situation in productive sectors and other areas susceptible of improvement through scientific and technological activities.

2. Diagnosis of the needs for scientific and technological activities.

3. Analysis of the scientific and technological system.

4. Balancing of requirements and possibilities.

Halty (1966) refers to the need for coordinating this type of analysis with the overall economic development effort of the nation:

"In establishing production goals and growth rates for itself, economic and social planning imposes productivity increments which must be met by and originate in technical innovation.

The technical advances required for this should constitute the minimum scientific and technological planning goals, since their nonfulfillment will be a limiting factor in the development process". (p. 7)

He also points out the relationships between educational planning, the planning of human resources, and scientific and technological planning; describing in detail how the four steps in the PAU planning methodology should be carried out, referring them to a base year and a planning period.

This "requirements and possibilities" methodology provides a very useful framework for scientific and technological planning. However, it appears to be difficult to apply without considerable additional planning efforts. For example, when establishing the requirements for scientific and technological activities imposed by economic and social development plans, it would be very difficult to determine which proportion of the growth specified in these plans should (or could) be achieved by the introduction of technological changes. In our analysis of the regression, disaggregation and production function methods, we found that isolating the effect of technological changes was not an easy task. This problem would probably become a major stumbling block when applying the requirements and possibilities method. Referring to the method proposed by Halty and the Pan American Union it is not very clear the way in which the balancing of requirements and possibilities is to be carried out. Coupling mechanisms need to be identified and the problems of shifting scientific and technological activities from one area to another so as to follow the economic and social requirements must also be taken into account. Halty (1966) is aware of these problems:

". . . . In fact, it is necessary to balance this demand (for science and technology) with a supply that is not always perfectly elastic because of the rigidity that specialization imposes upon the utilization of the manpower involved, and of the long period required to train scientific and technical personnel" (p. 22)

Chesnais (1970) analyses some of the difficulties and problems encountered by the OECD in applying their version of the requirements and possibilities method pointing out that it leaves out considerations regarding the scientific and technological knowledge available internationally and the possibilities of transferring technology.

In conclusiòn, the requirements and possibilities approach provides an overall framework within which to prepare plans for the development of the scientific and technological system, but it also leaves several questions unanswered which make it difficult to apply without complementing it with other planning activities.

Heuristic Methods

Heuristic methods can be considered as encompassing a variety of planning procedures that are based on common sense, and/or the use of rules of thumb (or heuristics). Their degree of sophistication is rather low, but they usually have a strong appeal and are based on logical considerations.

Carter (1968) proposes an heuristic method which could be appropriately termed the "bottleneck method." To begin with, Carter suggests that the assessment of science and technology plans should be based primarily on an analysis of their economic implications:

> ". . . if we do not have an economic policy about the distribution of scientific resources, we are unlikely to have any policy at all . . . . without an economic policy we have no point of departure, except perhaps some amalgam of the preferences of scientists (who are likely to be in favour of the further development of their own specialties)." (p. 38)

Based on these premises Carter proposes that the point of departure for scientific and technological planning should be defined by identifying the limiting factors (bottlenecks) that hold economic growth. His analysis is referred particuraly to the U. K. and, as an example, he considers the growth of British exports as the main limiting factor. Carter summarizes his suggestions as follows:

> "To sum up: I have proposed, as a starting point, an assessment of the economic requirements for science and technology in relation to the most serious limiting factor of the economy concerned. This is an act of long-term planning, and will yield an approximate idea of an appropriate distribution of scientific effort, first for applied research and development, thence for pure research and for the uses of scientists in production, sales, management, administration and education. The plan thus drawn up is only a starting-point for the country may wish to decide that, at the expense of the flow of material wealth, it will divert resources to satisfy pure intellectual curiosity. It will also need to look at the adequacy of its scientific effort to provide receiving stations for ideas from the rest of the world, and at the general balance between pure and applied research." (p. 43)

The methodology suggested by Carter could prove very useful in the initial stages of scientific and technological planning, however, once the long-term bottlenecks likely to hold back the economy are identified, it would be necessary to base scientific and technological plans on more solid ground and elaborate more on initial planning efforts. In a sense, the same comments that were made with respect to the deficiencies of the requirements and possibilities approach, would also be applicable to Carter's limiting factor method.

Another heuristic method is that suggested by Rexed (1968). Rexed begins with the premise that ". . . no country can present its research policy in a form which is comprehensive and completely and rationally analyzed. Too many factors are involved." (p. 123) He argues that a research policy and the subsequent plans could be defined in "a more or less articulate way" by observing and analyzing the actions of various institutions that are concerned with scientific and technological activities.

Referring particularly to the case of Sweden he reaches the conclusion that:

> "(A) brief review of some problems of research policy in a small country shows that it is not possible to consider research as a closed and connected system of activities. Instead, we must attempt to put research and its applications into a functional context, and in different spheres there are very different factors determining the scope, type and direction of a national effort. . ." (p. 136)

Having these problems in mind he suggests that the overall allocation of resources to the scientific and technological system should be arrived at by aggregation of individual research projects, defined by the institutions that would carry them out. These projects would be grouped by functional areas, with the exception of basic research which would be combined with education. In Rexed's words:

> "When research has been divided up among various functional areas, such as health, transport and energy production, there will be a residue of research which cannot be so allocated, and this will be the research that is usually combined with education. Even here, one can begin to ask what the minimum requirement of research is, even if one cannot state the optimum requirement.
>
> In this way, one reaches a definition of the research and developmental work needed for a country. The final science and development budget will then be an addition of all these sums, rather than a division of some initial sum of money." (p. 109)

The rationale behind Rexed's method is based on the concept that only those with executive responsibilities for the operation of some institution, organization, etc., know whether research or some alternative activity is the most efficient way of improving the way it operates. Therefore, decisions on the allocation of resources to research activities should be made by those individuals, departments, etc. in a decentralized way, rather than by some central authority:

> ". . . we should apply the principle that no research and development should be done unless a systems analysis shows that research will give a greater possibility for improvement than any other change in the total system - maybe rationalization, maybe a new road - could provide. Only if a comparative analysis of all the possible way to correct the situation shows that research is the most valuable one, in the short and long term, should one engage on it. But I feel that no department except that having executive responsibility in the field can decide." (p. 109)

Rexed's method presupposes the existence of a large number of individuals, or groups of individuals, who would be capable and prepared to make decisions on research activities in an efficient way. Although this may be the case for the more advanced countries in the world, it is certainly not the case for the less developed ones, where the number of institutions engaged in research tasks is rather small, and the lack of qualified manpower, both at the executive and the research level, is one of the major limiting factors for development.

It is also interesting to compare Rexed's views on the problems of formulating science policy in a small country like Sweden, with the UNESCO document Science Policy and Organization of Research in Norway (1966). Whereas Rexed arrives at the conclusion that only decentralized efforts are likely to lead to adequate policies and plans, the UNESCO document stresses the importance of coordination and direct action by the Norwegian government, both in the allocation of resources and on the formulation of research incentives for private industry.

Thus it is apparent that the methodology suggested by Rexed can only be applied when the nation under consideration has developed a network of research institutions, organizations, industries with research capabilities, etc. which could be able to formulate their own research plans in such a way that highly decentralized scientific and technological planning becomes possible.

Our review of Carter's "limiting factor" method and Rexed's "decentralization-aggregation" method, which can be considered as belonging to the category of heuristic methods, suggests that its general applicability might be rather limited. Furthermore, as long as they propose general rules of action which are not based on an assessment of the impact of alternative plans, they do not provide information on the relative merits of different courses of action.

The Matrix Method

This approach makes use of matrices to relate specific economic and project objectives to the scientific efforts required to support them. It generally relies on the use of two matrices, one relating scientific efforts with their possible results and another relating the results of scientific efforts to their impact on the project under study or the economy in general.

Cetron (1967) gives an account of a method used by the U. S. Navy in the determination of research programs, which is based on the use of the matrix approach.

The first matrix in Cetron's method related specific military capabilities or missions to the relevant technologies that may contribute to their success. The entries in this "mission-technology" matrix represent the "criticality" of a particular technolgy to the achievement of a determinate mission. Two "criticality coefficients" are developed for two different funding levels of each mission. A method that uses weights for missions combining them with the criticality indices is employed in order to develop a priority ordering for the technologies under consideration.

Then a second matrix which relates scientific activities with technologies is constructed. This science-technology matrix shows the importance of a particular scientific discipline for the adequate development of each relevant technology. The coefficients of this matrix are computed in a similar way to those of the mission-technology matrix. These coefficients are weighted by the relative priorities that were assigned to the technologies, obtaining in this way an ordering of scientific disciplines in which to do research. This method also yields the level of funding that should be assigned to each scientific discipline.

Another science and technology planning method that uses the matrix approach was suggested by Zammit (1968) and later proposed at a Latin American meeting of National Research Councils (UNESCO, La Política Científica en América Latina, 1968, p. 30). This method bears some resemblance to the input-output approach proposed by Johnson and Striner (1960).

It consists in constructing a science-science matrix which depicts the interrelationships between scientific disciplines; the relative influence of each of them on the other is reflected through the value of the coefficients. Then a science-use matrix is constructed which related the different scientific disciplines with the sectors of the economy, establishing the degrees of interdependence between them through the coefficients in the matrix. These two matrices are combined to determine, according to the importance of each economic sector, the relative priorities for research in each scientific discipline.

The final step on this method consists in analyzing, within the framework of scientific priorities determined by using the matrices, a set of research programs and projects in order to elaborate the scientific and technological plan.

These matrix methods appear to be very helpful in the determination of priorities for research areas in science and technology, but offer no guidelines in the evaluation of alternative ways of satisfying these priorities. They take economic objectives, or in the case of Cetron's method mission objectives, for granted and then proceed to determine the required inputs in the forms of scientific and technological activities. The level of coordination with the allocation of resources to the scientific and technological system is rather low, and although they offer a framework of priorities within which to analyze specific research projects, they provide no basis for the evaluation of alternative plans that may be geared to economic objectives other than those initially specified.

Relevance Tree Method

This approach gathers several planning methods which use "trees", or graphs without circuits, in order to depict the relationships between the different economic, functional and scientific aspects of research plans. These graphs are employed mainly as classifying or ordering tools, and are combined with the use of qualitative and quantitative techniques for evaluating the research activities associated with the terminal branches of the trees.

This approach was first used by Honeywell Corporation in their PATTERN (Planning Assistance Through Technical Evaluation of Relevance Numbers) technique. Jantsch (1967 pp. 215ff) gives a description of this technique together with a list of applications that have been made using it.

De l'Estoile (1968a, 1968b) has refined the initial methods of the relevance tree approach in his C. P. E. (Cost-Preference-Evaluation) technique, and has used it in the evaluation of military research programs, transportation research programs and a variety of other research activities. We shall describe briefly his method.

The basic elements in the de l'Estoile's method are the utility and the economic trees, the concept of "research operation', and the use of ordering rules (which produce partial order ratings) for defining priorities to be attached to the research operations.

The "economic tree" takes as point of departure a given national economic policy which defines several industrial sectors as areas of concentration. It is intended to show the logical processes linking research and development plans to the overall economic development planning efforts, as well as help in evaluating the possible contribution of research programs (particularly applied research) to the implementation of an economic strategy and the attainment of its objectives.

All the problems of determining the relative contribution of research and development to the attainment of economic objectives appear at this stage. De l'Estoile is well aware of them and, in fact, suggests that the use of economic trees with merit ratings associated to the branches would circumvent these difficulties:

> "To what extent? (can research programs contribute to economic development). That brings up the irritating problem of profits from expenditures on research, which resist every attempt to quantify by traditional methods, in particular the residual factor in the production functions. Hence the notion of using trees to compare what is not directly comparable, namely the relative utility of the various research programmes. Selection of the criteria for rating the tree is obviously a crucial point. How? Preparing the tree would be a task of formidable complexity were it not for two assumptions which. . . suggest a simplified tree:
>
> We are concerned with the implementation of an economic strategy, not with the overall planning of development in its multiple aspects. . . .
>
> We are concerned with the linking effects of technological innovation to this selective economic strategy." (1968b, p. 26)

Thus it appears that de l'Estoile gets around problems of evaluating the impact of research programs by taking an economic strategy for granted and working backwards to establish the research requirements for it. In a sense this resembles the requirements and possibilities approach we examined before. The price to pay for these simplifying assumptions is that no feedback is possible form the formulation of economic strategies, except by constructing a new tree from the beginning, which brings us back to the initial problem.

The elaboration of the economic tree proceeds in two stages. First, it is necessary to construct a "supporting tree" which shows the interrelationships between economic agents in the nation, the products they exchange, the processes, and so on, until a research operation is identified. The suggestion by de l'Estoile is to include producer and user branches in the tree, in order to show through multiple relationships to relative economic importance of each research operation to be evaluated.

The second stage produces the "rating tree" which attaches priorities to each branch in a qualitative way, depending on their possible contribution to the economic objectives. There are three criteria for rating each branch and its terminal research operation used by de l'Estoile: contribution to growth target, scientific merit, and the importance attached to it by the selective economic development strategy. These ratings are combined by an ingenious procedure in order to yield a priority for each research operation.

"The utility tree" takes overall national objectives, relating them to means for achieving them. This is done in such a way as to obtain, at the end of each branch, research operations that would correspond to those identified by the economic tree. For example, a supporting utility tree could take the national objectives of providing food, clothing, housing, etc. to the nation. The clothing objective could be attained by a variety of means, i. e., through the use of woven and non-woven textiles; the non-woven in turn could be produced from natural or synthetic materials; and so on, until a research operation is finally defined.

The utility rating tree is constructed by attaching qualitative utility measures to the research operations in a similar way as for the economic tree.

A national research and development plan is then assembled by selecting the research operations identified at the end of each branch for both trees and arranging them in order of priority of combined economic and utility ratings.

Piganiol et. al. (1967) have taken the relevance tree method of de l'Estoile and developed it further, adapting it to the needs of developing countries. They use both the economy and the utility trees and combine them in order to obtain a single rating for research operations. Their evaluation of economic merit is based on a cost/benefit analysis for each terminal branch (research operation) of the economic tree, and their evaluation of the utility introduces the concept of time, taking into account an estimate of delays between research needs and results from research activities. They summarize their own approach as follows:

> "(the plan) should be compiled in three stages:
>
> The first will be the inventory of development needs prepared from knowledge already obtained or to be obtained (UTILITY GRAPH).
>
> The second will be an analysis of the adequacy of various objectives thus determined, in relation to the country's economic options (ECONOMY GRAPH).

The third consists of indentifying priority research programmes by combinative synthesis taking into importance the scientific importance of the research." (p. 5).

In this way they define several types of research activities, according to whether they have high or low economic potential, great or small utility, and great or little scientific importance. They recommend that developing countries should concentrate on research activities that have high ratings on the economic and utility criteria.

The relevance tree approach was designed with the aim of circumventing the need to quantify the economic effect of alternative plans for the development of the scientific and technological system. It achieves its objective by using graph techniques that show the interrelations between economic and research objectives, and qualitative ratings in order to establish the priorities for research tasks to be included in the plan. However, as long as the process of deriving trees is a difficult and complex one, several simplyfying assumptions have to be made. The restrictions imposed by these assumptions do not permit to evaluate the effect of alternative plans for the development of the scientific and technological system, because each tree is constructed on the basis of a specified economic development strategy. The relevance tree approach imposes a one-way evaluation process, from economic objectives to research and development objectives, it does not explicitly provide for an interaction in the opposite direction.

<u>Summary</u>

In this part of the report we have reviewed briefly a sample of the literature relevant to science and technology policy-making and planning. The first three sections examined some general suggestions made on this subject and on the role of science and technology in developing countries.

Section 4, the most extensive, reviewed several methods that have been used or proposed for scientific and technological planning. These were divided into two main approaches, the quantitative and the non-quantitative, based on whether the method under review emphasized or or the other aspect of scientific and technological planning.

Under the heading of quantitative approach, we considered cost/benefit analysis, input/output analysis, regression analysis, dissaggregation methods, production function methods and the general approach followed by Professor Mansfield. Methods in the non-quantitative category included the requirements and possibilities method advocated by the OAS and the OECD, heuristic methods, matrix methods and the relevance tree method. For each of them a short description and a critique of its main feature were presented.

It is rather difficult to single one, or even a few, of these methods as better than the others. By varying the circumstances under which scientific and technological planning takes place, any of them could be made to appear as the most convenient method. Nevertheless, it would be safe to assert that a combination of a non-quatitative method to provide a frame of reference, and one or two quantitative methods to provide ways of estimating more precisely the effect of alternative plans, would constitute a more comprehensive approach to the difficult problem of planning scientific and technological activities.

Part V: Conclusion: Characteristics of an Idealized Planning Methodology

1. Introduction

In this last section of the report we shall gather some of the observations made in the four preceeding parts. We shall also look at the tasks that lie ahead if the concepts and ideas suggested in this document are to become guiding principles in the development of a planning methodology for scientific and technological activities, particularly in developing countries.

Our review of the vast literature on the subject of scientific and technological policy-making and planning led us to the conclusion that few theorizing efforts had been made in the direction of conceptualizing the activities of research and development, transfer of technology, normalization, technical services, etc. as a total and interrelated system. We also found few references that included scientific and technological activities in the context of the nation-system at large. Therefore, our initial efforts in Parts I and II were devoted to providing such a framework for analysis, taking the nation as a system and examining in further detail the scientific and technological subsystem. Our conceptualization of these systems and subsystems was heavily influenced by the earlier works of Ackoff, Machlup and Trist.

These conceptual models are offered as a starting point for data gathering activities and for the development of new planning methods. This is particularly relevant to countries in which these two types of efforts are not fully under way yet. Hopefully, they should help to avoid some of the pitfalls and errors made by the more advanced countries that lacked a comprehensive systems approach to scientific and technological planning when their efforts began.

The conceptual models proposed have important implications with respect to data gathering. All too often we found authors lamenting that the lack of relevant data seriously diminished their capabilities of developing planning models. The traditional categories of basic research, applied research and development, virtually unchallenged for a decade (Ackoff is the exception), appear to be unsuitable for gathering data if the data are to be used in the construction of planning models.

The planning implications of the conceptual models we propose are manifold. Perhaps the best way to summarize them is in terms of the characteristics of an idealized planning methodology. An earlier effort in the definition of an "ideal" planning methodology was made by UNESCO (1966b, pp. 21-24). Their definition of system and the planning methodology followed closely concepts and ideas borrowed from control theory. The stages involved in UNESCO's ideal methodological scheme begin with the definition of the system, and then proceed with the evaluation of its initial state, the diagnosis of the processes involved, the prognosis of future states if present trends continue, the adoption of goals, the establishment of boundary conditions and the selection of a development model. The last two stages consider the choice of a strategy and the determination of institutional policies for implementing it.

Rather than define the characteristics of an ideal planning methodology along UNESCO's lines, we shall attempt to isolate a few implications that are derived from our analysis in this document. However, we must realize that the quest for this "ideal" is bound to be disappointing. By definition, an ideal is something that cannot be reached, but only approached without limit. Furthermore, there may be more than just one ideal planning methodology, different historical conditions, cultural patterns, and environments may require that the ideal planning methodology be defined in different terms for individual cases. These are the reasons why, rather than attempting to identify an ideal planning scheme, we shall try to identify some of its characteristics.

2. Some Characteristics of an Ideal Planning Method

The first characteristic of an ideal planning methodology is derived from the conceptualization of the S & T system as a subsystem of the nation at large. An ideal planning method should evaluate, at least qualitatively and if possible quantitatively, the effect of alternative plans on all the systems the S & T system is interconnected with. This includes not only the economic and educational systems, but also the cultural, political, demographic and physico-ecologial systems. Using Trist's terminology (c. f. section 4 of Part I) the planning method should be able to evaluate the impact of plans on the scientific and technological system's task environment. At a second level it is also desirable that it be able to identify the impact of alternative plans on the S & T system's contextual environment.

This characteristic imposes rather difficult problems for the development of a planning method. To our knowledge, no general satisfactory measure of output has been developed for the scientific and technological system. The intangible good "knowledge" poses complicated measurement problems, and therefore the methodology should either develop a new measure of output or attempt to identify the total impact of plans for the S & T system without measuring directly its output. We also find here the problems of defining an objective or welfare function for the nation as a whole. The use of indicators, such as the GNP per capita, has proven, until now, to be inadequate in defining welfare functions that would take into account the effect of alternative plans for the development of the scientific and technological system.

A second characteristic of the ideal planning methodology is derived from its <u>instrumental</u> nature. It should provide the necessary information for appropriate decision making in the S & T system. When analyzing the difference between policy-making and planning for the S & T system, we suggested that policy-making was mainly concerned with setting overall criteria and drawing guidelines for the development of the scientific and technological system, while planning was mainly concerned with the identification, formulation and evaluation of alternatives for development, making use of the criteria established by the policy makers. As long as criteria change, policies are modified and guidelines are altered continuously, the planning methodology should be flexible, adaptive, and, in addition, have the capability of making of planning an accumulative learning process.

This leads us to the third characteristic of an idealized planning methodology: it should be experimental. Ackoff and Waldo (c. f. section 2, part 4) have given the reasons for this, and we find ourselves in complete agreement with their arguments.

Descending to more operational levels, the idealized planning methodology should be able to evaluate the effect of pursuing different types of activities in the S & T system, and should also be able to evaluate the impact of using different sets of criteria for scientific and technological choices. The same considerations are applicable with respect to the development of the organizational infrastructure and the determination of resource allocation patterns. Therefore, it should use a multi-level approach, taking activities, institutions and resources, analyzing them in an iterative way, as was suggested earlier in section 3 of Part III.

Throughout this document, we have mentioned just briefly the influence of human factors on the functioning of the S & T system. However, another major characteristic of an ideal planning methodology is heavily dependent on human factors: its degree of implementability. Not only the methodology must be able to generate, formulate and evaluate alternatives, but also it must be able to be easily accepted and utilized by those making decisions that affect the scientific and technological system.

Finally, there is another characteristic of the idealized planning methodology that is not derived from any specific point discussed in this document, but rather from the overall approach we have attempted to take in this study. An idealized planning methodology must be essentially creative and innovative, both in the identification of alternatives and in the formulation of criteria for their evaluation. Originality is especially important in scientific and technological planning for less developed countries. Illich (1969) has stressed this point, suggesting that they should seek alternatives for their scientific and technological development that are radically different from those that were followed by the developed countries.

These are some of the characteristics that an idealized methodology for scientific and technological planning should have. Many more could be added, but we just limited ourselves to identifying some characteristics that are directly derived from the analysis that has taken the first four parts of this document.

3. Some Steps Towards the Idealized Planning Methodology

Our analysis in this document has been concerned mainly with the formulation of conceptual models and a review of planning methods suggested by other authors. This is to say, we have remained at a rather abstract level without introducing any real data from direct sources.

Before beginning the construction of planning methods that would approach the characteristics of the idealized planning methodology, we need a more concrete frame of reference. This requires the identification of a country or region to which the conceptual tools put forward in this document could be applied, taking into account the specific conditions prevailing there. To a certain extent, the work of Sanchez Crespo (1970), who has done a historical study of Latin America's industrial development and traced its main implications on the development of the scientific and technological system, constitutes an attempt to use a frame of reference based partially on the conceptual models suggested in this report, contrasting them with the scientific and technological reality of Latin America.

Nevertheless, it is possible to identify a few general steps to be taken, regardless of the area or region for which the planning method would be constructed. These refer to some developments in operations research and in the social sciences which provide the tools for approaching the characteristics of an ideal planning method.

The planning method should begin by recognizing the inherent complexity of the scientific and technological system and the other systems it is related to, attempting to deal with this complexity without reducing it. What is needed is an evolutionary planning methodology which will continuously approach the level of complexity of the real world and at the same time approach the characteristics of the idealized planning methodology.

Ackoff (1969) has suggested the concept of "artificial reality" as a method for developing theories and modeling extremely complex systems. It consists of abstracting the main features of a complex situation, constructing theories and models that explain this simplified version of reality. Once this is achieved, the simplified "artificial reality" is made more complex by introducing additional factors, and new theories are sought to explain it. This process is repeated several times moving each time closer to reality.

From the patterns identified in the development of theories for explaining these "artificial realities" that continuously increase their degree of complexity, Ackoff suggests that it may be possible to identify a "theory of theories", this is, a theory of how theories for explaining the artificial realities are generated. In the limit, this theory of theories would explain the process by means of which a theory to explain reality could be developed.

This approach can be adapted to the development of a planning methodology that would approach the real world and the characteristics of the ideal scientific and technological planning methods. In this case, instead of a "theory about theories" we would have a "plan for developing planning methods", identified from the pattern followed by planning methods that are suitable for increasingly complex "artificial realities" that are less complex than the scientific and technological system itself.

Many roads are open for the development of these planning methods that would deal with increasingly complex representations of the S & T system. There are a variety of mathematical and statistical techniques that could be incorporated as part of the planning methodology that would evaluate the overall impact of alternative plans for the development of the scientific and technological system. Besides those already mentioned in our review of the literature, we have the possible use of Bayesian procedures to estimate the output of the S & T system, and the use of factorial or fractional factorial experimental designs for evaluating the effect of alternative ways of channeling resources through institutions. Also, mathematical programming methods, models for evaluating organizational efficiency, and simulation models are available as possible building blocks for the construction of planning methods for the S & T system. Therefore, an additional task in the development of a planning methodology would be that of identifying and evaluating the possible tools to be used as building blocks.

4. Summary

In this last part of the report we have suggested the possible ways in which the results of this report may be utilized. Some characteristics of an idealized planning methodology have been identified and an outline of how to develop it has been suggested. We have also stressed the importance of contrasting the conceptual models proposed here with the real world.

The problem of a planning methodology for the development of the scientific and technological system, particularly in a developing country, can be stated in general terms as that of constructing a planning method for an inherently complex system whose output cannot be directly measured, for which very little data are available in the adequate form, and which needs to be flexible, adaptive, and essentially experimental.

BIBLIOGRAPHY

ACKOFF, Russell. "Specialized Versus Generalized Models in Research Budgeting." Research Program Effectiveness. Edited by Yovits, et. al. New York: Gordon Breach Science Publishers, (1966).

ACKOFF, Russell. "Operational Research and National Science Policy". Decision Making in National Science Policy. Edited by De Reuck, et. al. London: J & A Churchill Limited, (1968).

ACKOFF, Russell. "The Role of Research in Underdeveloped Countries." Operations Research XVI (1968), 717-726.

ACKOFF, Russell. Class Notes from Course OR 601, University of Pennsylvania, (1969).

ACKOFF, Russell. A Concept of Corporate Planning. New York: John Wiley and Sons, (1970).

AMANN, Ronald. "The Soviet Research and Development System: The Pressures of Academic Tradition and Rapid Industrialization." Minerva, VIII (1970), 213-241.

ARROW, K. J.; CHENNERY, H. B.; MINHAS, B. S. and SOLOW, R. M. "Capital-labor Substitution and Economic Efficiency." The Review of Economics and Statistics, XLIII (1961), 225-250.

BARANSON, Jack. "Role of Science and Technology in Advancing Development of Newly Industrializing Countries." Socio-economic Planning Sciences, III (1969), 351-383.

BHAGWATI, Jagdish. The Economics of Underdeveloped Countries. New York: McGraw-Hill, Inc., (1966).

BROWN, Murray. On the Theory and Measure of Technological Change. Cambridge: Cambridge University Press, (1966).

BROWN, M. and DE CANI, J. "Technological Change and the Distribution of Income." International Economic Review, IV (1963), 289-309.

BROWN, M. and CONRAD A. "The Influence of Research and Development in CES Production Relations" in National Bureau of Economic Research: The Theory and Empirical Analysis of Production, New York, (1967).

CARTER, C. F. "The Distribution of Scientific Effort." Criteria for Scientific Development, Public Policy and National Goals. Edited by E. Shils. Cambridge: MIT Press, (1969).

CECIC, (Comisión Ejecutiva, Consejo Interamericano Cultural) Viña del Mar Conference, (May 1969), Document 2.

CETRON, Marvin. "QUEST Status Report." IEEE Transactions on Engineering Management, EM-XIV (1967), 51-62.

CORNBLIT, Oscar. "Factors Affecting Scientific Productivity: The Latin American Case." Paper presented at the UNESCO Round Table on Social Research Policy and Organization, Paris, France, (1969).

DE l'ESTOILE, H. "Choice of Criteria for a Research and Development Strategy." Paper presented at the UNESCO Meeting of Experts on the Role of Science and Technology in Economic Development, Paris, France, (1968).

DE l'ESTOILE, H. "La Programmation de la Recherche Appliquée." Le Progrès Scientifique, CXVIII (1968), 8-50.

DE SOLLA PRICE, Derek. Little Science, Big Science. New York: Columbia University Press, (1963).

DEDIJER, Stevan. "Measuring the Growth of Science." Science, CXVI (1962), 781-788.

DEDIJER, Stevan. "Underdeveloped Science in Underdeveloped Countries." Criteria for Scientific Development Public Policy and National Goals. Edited by E. Shils. Cambridge, Massachusetts: MIT Press, (1969).

DENISON, Edward. The Sources of Economic Growth in the United States and the Alternatives Before Us. New York: Committee for Economic Development (1962).

DENISON, Edward. Why Growth Rates Differ. Washington: The Brookings Institution (1967a).

DENISON, Edward. "Sources of Postwar Growth in Nine Western Countries. The American Economic Review, LVII (1967b), 1-8.

DROR, Yehezkel. "A General Systems Approach to User of Behavioral Sciences for Better Policy Making." (RAND Memorandum P-4091, (May 1969).

DUCKWORTH, W. E. "The Determination of Total Research Effort." Operational Research Quarterly, XVIII (1967), 359-374.

ECKAUS, R. S. "Technological Change in the Less Developed Areas". Development of Emergent Countries an Agenda for Research. Washington: The Brookings Institution (1962).

FAWCETT, Sherwood. "La Adaptación de la Tecnología como Medio de Alentar al Desarrollo Económico." El Proceso de Industrialización de América Latina. Washington: Inter-American Development Bank (1969).

FOSTER, C. D. "Cost-Benefit Analysis in Research." Decision Making in National Science Policy. De Reuck, et. al. London: J & A Churchill Limited (1968).

FREEMAN, Christopher. The Measurement of Scientific and Technological Activities. Paris: UNESCO (1969).

FRIEDMANN, John. "A Conceptual Model for the Analysis of Planning Behavior." Administration Science Quarterly, XII (1967), 225-252.

FRIIS, Henning. "Division of Work Between Universities, Independent Institutes and Government Departments." Social Sciences Information, V (1966), 5-11.

FURTADO, Celso. Development and Underdevelopment. Los Angeles: University of California Press (1962).

GAMBA, Juan Carlos. "Documentos para los Estudios de Base 3 y 4." Technological Development Unit, General Secretariat of the OAS (1970).

GARGIULO, Gerardo and MOYA, Alejandro. "Estudios Sobre Política y Planificación de la Ciencia y la Tecnología." Technological Development Unit, General Secretariat of the OAS (1970).

GRILICHES, Zvi. "Production Functions in Manufacturing Some Preliminary Results" in National Bureau of Economic Research: The Theory and Impirical Analysis of Production. New York (1967).

GROSS, Bertram. "The State of the Nation, Social Systems Accounting." Social Indicators. Edited by R. Bauer. Cambridge, Massachusetts: MIT Press (1966).

GRUBER, William and MARQUIS, Donald, eds. Factors in the Transfer of Technology. Cambridge, Massachusetts: MIT Press, (1969).

HALTY, Máximo. "Scientific and Technological Policy and Planning." Department of Scientific Affairs, General Secretariat of the OAS, (1966).

HODARA, Joseph B. Condiciones e Indicadores de Productividad Científica. México: Instituto de Investigaciones Sociales de la Universidad Autonóma de México, (1969).

ILLICH, Ivan. "Outwitting the 'Developed' Countries." The New York Review of Books, XIII (1969).

ISARD, Walter. General Theory: Social, Political, Economic and Regional. Cambridge, Massachusetts: MIT Press, (1969).

JANTSCH, Eric. Technological Forecasting in Perspective. Paris: OECD, (1967).

JANTSCH, Eric. "Integrative Planning of Technology." Perspectives of Planning. Edited by E. Jantsch. Paris: OECD, (1969).

JOHNSON, Ellis and STRINER, Herbert. "Research and Development, Resources Allocation and Economic Growth." Paper presented at the Meeting of the International Federation of Operational Research Societies, Aix-en-Provence, France, (1960).

KATZ, Jorge. Production Functions, Foreign Capital and Growth in the Argentine Manufacturing Sector 1946-1961. Buenos Aires: Instituto Torcuato Di Tella, (1968).

KING, Alexander. Proceedings of the Special committee on Science Policy, The Senate, Canada (Phase 1), (1967-1968), 226ff.

LIBIK, George. "The Economic Assessment of Research and Development." Management Science, XVI (1969), 23-64.

MACHLUP, Fritz. The Production and Distribution of Knowledge in the U.S. Princeton: Princeton University Press, (1962).

MADDOX, John. "Choice and the Scientific Community." Criteria for Scientific Development, Public Policy and National Goals. Edited by E. Shils. Cambridge, Massachusetts: MIT Press, (1969)

MAHEU, Rene. National Science Policies in Countries of South and Southeast Asia. Paris: UNESCO, (1965) (Chapter 3).

MANSFIELD, Edwin. The Rate and Direction of Inventive Activity. Report of the National Bureau of Economic Research. Princeton: Princeton University Press, (1962), 188-193.

MANSFIELD, Edwin. Industrial Research and Technological Innovation. New York: W. W. Norton and Company, (1968).

MINASIAN, Jora R. "The Economics of Research and Development." The Rate and Direction of Inventive Activity. Report by the National Bureau of Economic Research. Princeton: Princeton University Press, (1962), 93-141.

NORDHAUS, William D. Innovation, Growth and Welfare. Cambridge, Massachusetts: MIT Press, (1969).

OECD. Proposed Standard Practice for Surveys of Research and Development. Paris: (1963).

OECD. The Residual Factor and Economic Growth. Paris: (1964).

PAN AMERICAN UNION, Departament of Scientific Affairs. Methodology for Scientific and Technological Planning. Washington: (1968).

PARSONS, Talcott. Societies, Evolutionary and Comparative Perspectives. Englewood Cliffs, N. J.: Prentice Hall Inc., (1966).

PARSONS, Talcott, and SHILS, E., eds. Toward a General Theory of Action. Cambridge, Massachusetts: Harvard University Press, (1951).

PARSONS, Talcott; SHILS, E.; NALGILE, K. and PITTS, J., eds. Theories of Society. New York: Free Press of Glencoe, (1961).

PIGANIOL, P.; de HEMPTINNE Y. and VU CONG L. National Development, Technological Innovation and Research Programming extracted from "Methods and Means for Promoting Scientific Activity in Tropical Africa." Transaction of the Symposium on Science Policy and Research Administration, Yaunde Cameron, (1967).

POWELL, C. F. "Priorities in Science and Technology for Developing Countries." The Science of Science. Edited by H. Goldsmith and A. Mackay. Harmondsworth Middlesex: Penguin Books, (1966).

PRICE, Don K. The Scientific Estate. Cambridge, Massachusetts: Harvard University Press, (1965).

REISS, Howard. "Human Factors at the Science-Technology Interface." Factors in the Transfer of Technology. Edited by W. Gruber and D. Marquis, Cambridge, Massachusetts: MIT Press, (1969).

REXED, Bron. "Observation on National Science Policy in Sweden." and "General Discussion." Decision Making in National Science Policy. Edited by A. de Reuck, et. al. London: J. and A. Churchill Limited, (1968).

ROTTENBERG, Simon. "The Warrants for Basic Research." Criteria for Scientific Development, Public Policy and National Goals. Edited by E. Shils. Cambridge, Massachusetts: MIT Press, (1969).

RUBINSTEIN, Albert and YOUNG, Earl. "An Analysis of Alternative Strategies for Organizing the Applied Research Activities of Developing Countries." Recherche Operationelle et Problemes du Tiers Monde. Paris: Dunod, (1964).

SANCHEZ CRESPO, Alberto. Esbozo del Desarrollo Industrial de América Latina y de sus Principales Implicaciones sobre el Sistema Científico y Tecnológico. Washington, D. C.: Technological Development Unit of the OAS, (1970).

SHILS, Edward, ed. Criteria for Scientific Development, Public Policy and National Goals. Cambridge, Massachusetts: MIT Press, (1969).

SIMMONS, John. "Technology and Education for Economic Development." Science and Technology in Developing Countries. Edited by C. Nader and A. B. Zahlan. Cambridge: Cambridge University Press, (1969).

SOLOW, Robert. "Investment and Technical Progress." Mathematical Methods in the Social Sciences 1959. Edited by Arrow, K. et. al. Stanford: Stanford University Press, (1959).

SOMMERHOFF, Gerhad. Analytic Biology. Oxford: Oxford University Press, (1950).

SPENCER, Daniel and WORONIAK, Alexander. "The Feasibility of Developing Transfer of Technology functions." Kyklos, XX (1967), 431-459.

SZAKASITS, G. D. "Various Approaches to the Problem of the Integration of Scientific and Economic Plans into General Plans." Paper presented at the meeting of Experts on the Role of Science and Technology in Economic Development, UNESCO, Paris, (1968).

TOULMIN, Stephen. "The Complexity of Scientific Choice I and II." Criteria for Scientific Development, Public Policy and National Goals. Edited by E. Shils. Cambridge, Massachusetts: MIT Press, (1969).

TOULMIN, Stephen. "Innovation and the Problem of Utilization." Factors in the Transfer of Technology. Edited by W. Gruber and D. Marquis. Cambridge, Massachusetts: MIT Press, (1969).

TRIST, Eric. "Some Social Research Institutions in Different Countries." (1967). To appear in Main Trends of Research in the Sciences of Man, UNESCO.

TRIST, Eric. "Proceedings of the Special Committee on Science Policy of the Senate, Canada." XXXIX, Ottawa, Canada, (1969). Also Appendix 39.

TRIST, Eric. "Types of Output of Research Organizations and their Complementarity." Paper presented at the UNESCO Conference on Policy and Social Research. Paris, (1970).

UNESCO/CASTALA. Find Report of the Conference of the Application of Science and Technology to the Development of Latin America. (1965).

UNESCO. "Consideration on the Concept of Science Policy." Paper presented at the Meeting of the Coordinators of Science Policy Studies, Karlovy-Vary Czechoslovaquia, (1966a).

UNESCO. "Science Policy and Organization of Research in Norway." Science Policy Studies, No. 4. Paris, (1966b).

UNESCO. "Structural and Operational Schemes of National Science Policy." Science Policy Studies, No. 6. Paris, (1967).

UNESCO. The Measurement of Scientific and Technological Activities. Paris, (1969).

UNESCO. "La Política Científica en América Latina." Science Policy Studies, No. 14. Paris, (1969).

UNITED NATIONS Advisory Committee on Science and Technology. Third Report. New York: (1966).

VICKERS, Sir Geoffrey. "Proceedings of the Special Committee on Science Policy on the Senate, Canada." XXXIX, Ottawa, Canada, (1969). Also Appendix 38.

WALDO, Dwight. "Planning and Administration for viable Policies: The Perspective of Official Responsibility." Science and Technology in Developing Countries. Edited by C. Nader and A. Zahlan. Cambridge: Cambridge University Press. (1969).

WILLIAMS, E. "Research Expenditures and Economic Growth: What should we Expect?" in Criteria for Scientific Development, Public Policy and National Goals. Edited by E. Shils, Cambridge: MIT Press, 1969.

ZAMMIT, Ann. Metodología para el Planeamiento de Ciencia y Tecnología, Santiago, Chile: Centro de Planeamiento de la Universidad de Chile, 1968.

STUDIES ON SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT

Studies Published

1. Primer Seminario Metodológico sobre los Estudios de Base para la Planificación de la Ciencia y la Tecnología. (Alberto Sánchez Crespo).

2. Importación de Tecnología, Gastos Locales de Investigación y Desarrollo y Progreso Tecnológico en el Sector Manufacturero. Jorge Katz.

3. Compilación de Datos Científico-Tecnológicos en América Latina. (Juan Carlos Gamba).

4. Patentes e Importación de Tecnología. Daniel Chudnovsky y Jorge Katz.

5. Notes on the OAS and OECD Methodologies for Determining Requirements for Science and Technology. (Francisco Sagasti).

6. Patentes y Actividad Inventiva Individual. Daniel Chudnovsky y Jorge Katz.

7. A Systems Approach to Science and Technology Policy-Making and Planning. (Francisco Sagasti).

Studies in Preparation

8. El Empresario y la Innovación. Marco Teórico de Investigación. Ruth Sautu y Catalina Wainerman.

9. Inventario Científico-Tecnológico Nacional. Marco General y Definiciones. (Hugo M. Williams).

Note:

The authors in parentheses are specialists of the Planning and Studies Division of the Department of Scientific Affairs of the Organization of American States.