A SCIENTIFIC APPROACH TO TECHNICAL AND ECONOMIC DEVELOPMENT PROGRAMS

by

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Submitted for Discussion at the International Conference on Science in the Advancement of New States, at Rehovoth, Israel, August 1960.

ABSTRACT

It is generally recognized today that the impersonal market forces do not lead an ailing economy along its optimum path of growth. To overcome well known obstacles of imperfections and indivisibilities, long range technical and economic programs are necessary.

Conventional economic development programs may be grouped in two categories. The first category consists of programs which aim at enhancing the economic activity of a nation without attempting to alter the sectoral structure of the Country's economy. The second category is composed of programs based on the recognition of certain pathological conditions (e.g., mass unemployment, low productivity, etc.). The programs attempt to eliminate these conditions by means of government-sponsored projects and encouragement of private initiative.

Both types of programs are fundamentally defective: the first type because it assumes, a priori, an optimum distribution of the productive forces: the second type because the choice of the objective is axiomatic, and not a result of a scientific study of the economy.

A third alternative is what the authors call "National, Technical, and Economic Development Programs". These programs have scientific merits as applications of the modern theory of economic growth to the problems of underdeveloped countries. The development of such programs involves three stages of study.

First, a detailed study of the presently existing economic structure. This includes the establishment of a representative number of production and consumption functions, and the detailed estimation of the available labor force, the level of the natural resources, etc.

Second, a consideration of all possible combinations of the economic activities, and mathematical determination

of the optimum combinations (i.e., determination of the dynamic Pareto efficiency curve).

Finally, if the existing situation differs from the optimum, the program should suggest several procedures, each based on different value judgements, for eliminating the gap. The final choice of a particular procedure is, of course, left to the responsible government.

The demands of such studies in technical, mathematical, and computational skills make a close co-operation between scientists of a large variety of specialties essential to the implementation of the program.

1. INTRODUCTION

All statesmen accept the proposition that the economic growth of a Country can be influenced favorably by a well conceived plan of production and distribution of commodities.

This is particularly true for the case of new States or Countries under development where it is generally recognized that the impersonal market forces cannot lead the economy to its optimum path of growth. On the one hand, the pricing system fails to provide the proper coordination of investment decisions towards a high economic level (9) and on the other hand, the existence of strong indivisibilities on the production and savings side, technologically external economies and complementarity of Demand render the functioning of the Capital Market most difficult (6). The "take off" of an underdeveloped country is achieved only through thorough scientific planning aiming at (4, 5, 10):

a. The elimination of the elements which obstruct the smooth functioning of a flexible economic system and

b. The achievement of optimum allocation of resources with full use of the human and material potential of the Country.

These two general aims are common in most economic programs. However, in many cases, the specific objectives are set forth a priori and arbitrarily and there is no quarantee that they will necessarily lead to an overall optimum economic structure within the scope of the general aims.

The purpose of this communication is to describe a scientific approach to technical and economic development programs. The great advantage of this approach is that the optimum combinations of economic activities in a Nation are determined analytically, without restrictions imposed by

pre-established value judgements. Furthermore, procedures for the attainment of each optimum combination are determined on the basis of technical and economic criteria. Once all the optimum combinations have been determined, it is then up to the responsible government to select, by means of value judgements, a particular optimum combination and a particular procedure for attaining it.

Chapter 2 of the paper describes the two conventional types of economic development programs and discusses their respective merits and defects. The principles of "National, Technical, and Economic Planning" are set forth in Chapter 3. Finally, in Chapter 4, the paper emphasizes the contribution of the scientist in the implementation of National Planning.

2. CONVENTIONAL ECONOMIC DEVELOPMENT PROGRAMS

Depending on the type of specific objectives and the manner of application of the theory of economic planning, development programs which have been put forth in the past may be grouped in the following two categories:

a) Programs of Sectoral Enhancement

Programs of this category aim at enhancing the economic activity of a Nation without attempting to alter the sectoral structure of the country's economy. The programs which were recently developed by special teams of the United Nations Organization, like the Economic Commission for Latin America, belong to this category. The essential assumption involved in Programs of Sectoral Enhancement is that the presently existing allocation of resources is more or less correct. The specific objective is then to adjust the fiscal and monetary policies in such a manner that the rate of growth of the various economic activities is proportionately increased.

b) Programs of Sectoral Rectification

This category is composed of programs based on the recognition of certain pathological conditions (e.g., mass unemployment, low productivity, etc.) due to sectoral maldistribution of the productive forces. The specific objective of the programs is to eliminate the pathological conditions by means of government-sponsored projects and encouragement of private initiative. The programs which were recently developed in Southern Italy and in India belong to this category.

It is felt that both types of programs are fundamentally defective. The defects lie not in the methods used in the formulation of the programs, but in the fact that certain axiomatic propositions are adopted at the outset of the studies. Programs of "Sectoral Enhancement" assume, a priori, that the existing distribution of the productive forces is optimum. Such an assumption, often incorrect even in well advanced

economies, is certainly not acceptable in underdeveloped countries. The maldistribution of the resources is usually the most important fault in a backward economy. Thus, programs of this type tend to perpetuate the structural weakness of the economy.

Programs of "Sectoral Rectification" are an improvement over programs of the first category in the sense that the sectoral maldistribution is recognized and steps are taken to rectify the existing allocation of activities. However these programs are also defective because the choice of the specific objective is axiomatic and not a result of scientific analysis of the economy. Such pre-established objectives are not commendable. Objectives which are set out arbitrarily may well be incompatible with the general aims of economic planning. For example, elimination of under-employment does not necessarily conform with maximization of the National Product; or, rapid industrialization is not always compatible with absorption of the entire labor potential. Consequently, "Sectoral Rectification" programs do not always lead an economy to its optimum condition, nor do they guarantee a full utilization of the natural resources.

The preceding arguments indicate that neither type of program is recommendable for application to new or developing States. What is needed is a scientific program which starts with the general aims defined previously, namely: a) Elimination of the elements which obstruct the smooth functioning of the economy. b) Achievement of optimum allocation of resources with full use of the human and material potential of the Country. No specific objectives (such as establishment of particular industries, shift from one activity to another, etc.) are defined arbitrarily at the beginning. Instead, the distribution of productive forces which yields optimum rate of growth while satisfying the constraints of total employment, maximum utilization of natural resources

etc., are first determined analytically as explained in the following chapter. The specific objective is the attainment of one of the optimum distributions.

The methodology for developing programs of this type is described in the next chapter.

3. NATIONAL, TECHNICAL, AND ECONOMIC PLANNING

A. Definitions

Before stating the principles of National, Technical, and Economic Planning, certain technical terms are defined. Since the terms used here are part of the standard terminology in economics, it should be emphasized that the present section is written primarily in the interest of the non-economist.

In order to study quantitatively the economic condition of a Country, it is convenient to divide the overall production (of commodities or services) into a number of sectors. These divisions are termed the production sectors. The chemical industry, the wheat production, the road construction industry are all possible production sectors.

It is also convenient to divide the available resources (labor, capital, raw materials, etc.) into a number of groups. These groups of resources are termed the production factors. Deposits of a particular ore, capital for building and construction, labor for the steel industry, may be defined as production factors.

It is clear that a particular output quantity of a production sector may be produced by various combinations of production factors. If the relationship between the output of the production sectors and the production factors used up by each sector is expressed in functional form, one obtains the technological functions of production or, simply, the production functions.

Any combination of output of n production sectors may be described by a point in the n-dimensional space whose co-ordinate axes are the n-sectors. The particular point which corresponds to the existing combination of production factors is termed the operating point of the economy. A large number of combinations of production factors in general forms a volume in the n-dimensional space. The locus of points corresponding to maximum total production with full utilization of resources is a surface which is termed the optimum production surface (Pareto efficiency locus).

The overall consumer population may be divided into a number of consumer sectors (high income urban sector, medium income rural sector, etc.). The consumption functions are equations relating the consumption (or demand) of each commodity to the corresponding price level and to the income of the various consumer sectors. The consumption or demand surface is a geometric representation in the n-dimensional space of combinations of consumption functions which satisfy optimizing constraints analogous to those specified in defining the optimum production surface.

The facility to produce one commodity at the expense of producing a second commodity, the total available resources being constant, determines the so called "shadow price" of the first commodity with respect to the second. In a theoretically free economy, that is, an economy which is free of monopolistic tendencies, fiscal and monetary restrictions, protected products and professions, etc., the shadow prices are also the market prices, i.e., the prices of the goods in the market.

Having defined these few terms, it is possible to proceed with the statement of the general principles of National Planning.

B. General Principles

The formulation of National, Technical and Economic Programs involves three stages of study.

First, a detailed study of the presently existing economic structure. In order to understand fully the interrelationship between the variables which define the economic system, one must do the following:

(i) Determine all the production factors. In other words, specify in type and quantity the available labor, capital, and material resources. Analytically, if we let K_{ji} represent the quantity of resource j (labor, capital, raw materials, etc.) required to produce commodity i, this part of the study establishes the total available resource K_j. Thus:

$$K_j = \sum_{i=1}^{n} K_{ji} + K_j^a \qquad \begin{matrix} i = 1,2.....n \\ j = 1,2.....m \end{matrix} \qquad (1)$$

where K_j^a = unused quantity of resource K_j.

(ii) Study all the combinations of the National production which are technically possible and determine the production factors needed for each combination. Analytically, this corresponds to the determination of n equations of the form:

$$Q_i^{(s)} = f_i(K_{1i}, K_{2i}, K_{3i}.....K_{mi}) \qquad i = 1....n \qquad (2)$$

where $Q_i^{(s)}$ represents the quantity of commodity i supplied and f denotes its functional relationship to the resources.

(iii) Define and evaluate all the consumption functions. In other words, determine the dependence of the total demand of each product on the corresponding prices and on the level and distribution of the National Income. This may be expressed, for example, as follows:

$$Q_i^{(d)} = F_i(p_i, Y, D....) \qquad (3)$$

where $Q_i^{(d)}$ is the quantity of commodity i demanded, F_i denotes a functional relationship, p_i is the price level of i, Y is

the level of the National Income, and D is the distribution of the National Income.

The second stage of study involves the consideration of all possible combinations of production factors, and mathematical determination of the combinations which yield maximum National output (determination of the Pareto efficiency locus). Analytically, this stage of study consists of maximizing Eqs. (2), subject to the constraints imposed by the total available resources, Eqs. (1). It is important at this point to emphasize that for a realistic approach to the problem one must express K_{ji} as a function of time. In other words, it must be realized that an economy is a dynamic system.

It can be proved (3) that the solution of the extremum problem formulated above does not yield a unique optimum combination but an infinite number of combinations which, from the point of view of production, are all optimum.

The selection of one operating point out of the infinity of optimum combinations is determined by the Demand functions (Eqs. (3)). However this cannot be achieved without resorting to specific value judgments.

The reason why value judgments are necessary at this stage of the study can be justified as follows: Each point on the Pareto efficiency locus corresponds to a production level, a set of "shadow prices" (2,3), and a certain National Income. Given the shadow prices and the National Income, the demand functions clearly indicate that the assumed production can be consumed only when the Income Distribution has a definite value (see Eqs. (3)). Thus, the question of selection of an operating point reduces to the selection of a most desirable Income Distribution. The latter question cannot be answered scientifically. The choice of the final distribution of the National Product depends on the social philosophy of the political leaders and consequently it is a problem which can be answered only in terms of specific

value judgments.

The scientific program should simply determine a large number of optimum operating points, their associated Income Distributions and the economic growth potentialities that each point presents. Then if the established Income Distributions and growth potentialities are sufficiently diversified any likely political leadership of the Country in question will be able to select the operating point which is consistent with its political and social orientation.

The third and final stage of study is composed of a detailed comparison between the present state of the economy and the desired states on the Pareto efficiency locus. If the existing situation differs from the optimum (as the case is bound to be in under-developed Nations) the program should suggest procedures for arriving at optimum points. The final choice of a particular optimum point is, as mentioned above, a question of value judgments and must therefore be left to the responsible government.

C. Illustrative Example

The principles of the analysis just described are best understood by means of a two sector-two factor example. Consider an ideally simple economy which produces two commodities (X: consumption commodity, Y: capital commodity) using two production factors (A: capital stock, B: labor). The available total amounts of the two factors are represented by the perpendicular sides of a box-diagram (Fig. 1). Any point within the box, if oriented with respect to the lower left-hand corner, can be thought of as representing the amounts of the two factors used in the production of a given quantity of the first good (commodity X). All points representing the same quantity of commodity X lie on a curve which is called the isoquant (dotted curves X_1, X_2 .... etc.).

A point referred to the upper right-hand corner repre-

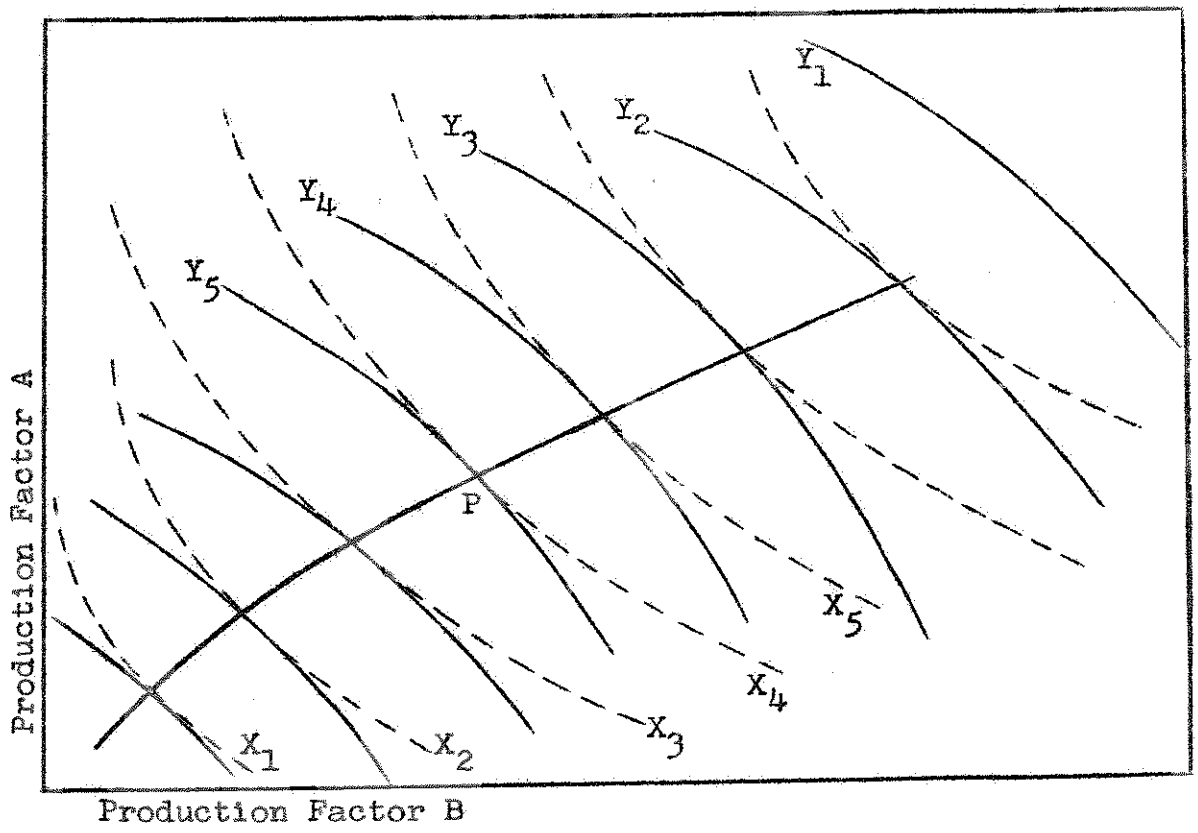

Figure 1. Construction of Pareto Efficiency Locus

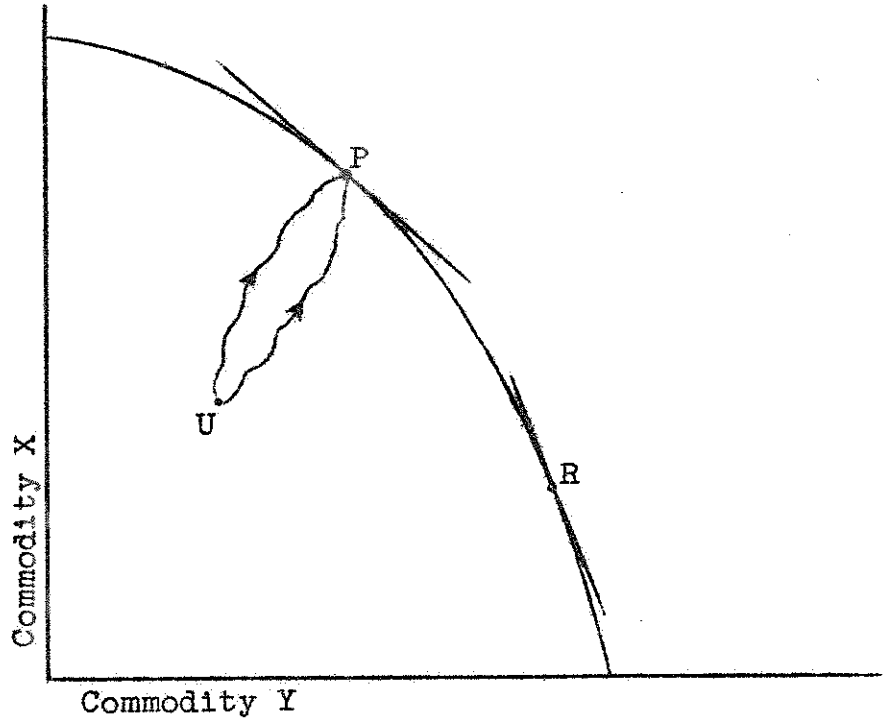

Figure 2. Pareto Efficiency Diagram

sents the allocation to the second good (commodity Y). The isoquants of Y are superimposed on Fig. 1 (full lines).

If one specifies the amount of one of the goods (quantity X_4, for example) thus restricting the combination of production factors A and B to lie on the isoquant line X_4, the optimum production of Y is given by the Y-isoquant which is tangent to X_4 (point P) and is $Y = Y_5$. The locus of all such points of tangency represents the infinity of optimum conditions. In a diagram in which the commodities are the axes, this locus is the optimum production surface, which in the 2-dimensional example is, of course, a plane curve. This is the so called Pareto efficiency locus (Fig. 2).

All points lying on the Pareto efficiency locus are operating points representing maximum National production and full utilization of resources. The slope of the tangent to the curve at any point represents, as already mentioned, the relative prices of commodities X and Y.

The next step is the determination of the most desirable point on the Pareto efficiency curve. Since all points on the curve are optimum from the point of view of production, a choice cannot be made on the basis of production considerations alone. Actually, arbitrary points (P,R...) should be selected and the corresponding shadow prices (i.e., slopes of Pareto curve at the point under consideration), National Income, Income Distribution (Eqs. (3)), and growth potentialities established. Then, by resorting to value judgments the most desirable Income Distribution and growth potential can be specified and thus in turn the most desirable point on the Pareto curve uniquely defined.

In an underdeveloped Country the operating point of the economy lies below the Pareto efficiency locus (e.g., point U in Fig. 2). The last part of the study consists of an

investigation of the reasons which make the economy operate so inefficiently and proposal of methods for moving from position U to a selected point (P or R) on the optimum production curve.

The procedure outlined in terms of the two factor - two commodity example is applicable without modification to the general i factor - n commodity case. Of course a graphical representation of the general case is impossible.

In what follows, each of the three stages of study outlined in section B are considered in more detail.

D. Methodology

(i) Study of Present Economy

In order to evaluate the total production and the production functions (Eqs. 1 and 2), it is convenient to divide the overall production into a number of sectors and production factors. The process of division into sectors is carried out on the basis of the experience of previous programs and after consideration of the conditions which are peculiar to the Country in question. The correct selection of sectors is an important aspect of the program. The number of sectors and production factors must be sufficiently large to be representative but at the same time not so large as to make the manipulation of the data unwieldy. Depending on the size and diversification of the economy, the number of production sectors may vary from 50 to 300; while the number of production factors may vary from 20 to 100.

This arbitrary division of the economy into production sectors and production factors forms the pattern on which the collection of data is based. A field research group collects the data required to establish the amount of each production factor which is used by each production sector. At the same time the group obtains information on the production factors which are not presently used (unexploited natural resources, unemployed labor, etc.). With this information the total

available resources (Eq. 1) and the existing relationship between production sectors and factors (Eq. 2) is established.

It was mentioned earlier that due consideration must be given to the dynamic nature of the economy. In connection with this consideration, studies must be made to predict the future capability of each production factor. Expected increase of labor force, increase of resources due to the formation of new industries suggested by the program, mobility of resources, facilities in technical education, effect of increase in one sector on the other sectors, expected changes in foreign trade evolving from the directions of the program in the Country under consideration and in other trading countries are a few of the studies which determine the time dependence of the production factors (1, 2, 8).

The evaluation of the demand equation (3) follows along similar lines. The consumers and the consumer goods must each be divided into a number of sectors. The task of the field research group is again to determine the demand on each commodity by each consumer population sector. Of course the dynamic aspects of this process must also be taken into account.

(ii) Determination of the Pareto Efficiency Locus

The technological relations of production are determined from the data collected by the field research group. Thus, for each production sector, the various combinations of production factors which are used in order to produce different quantities of a commodity are determined. The technological functions are usually expressed as exponential relations of the Cobb-Douglas type. In most cases the determination of the exponential coefficients requires the use of electronic computers.

The exponential functions obtained are next compared with analogous relations established in more advanced economies. The comparison may suggest possible improvements in

the evaluation of the production functions.

Once all equations (1) and (2) have been established, the combinations which yield a maximum National output subject to the constraints of full utilization of resources may be determined analytically. The theoretical aspects of extremum problems of this type have long been treated in the mathematical literature. The dynamic aspects of the economy are taken into account by expressing the production factors as time dependent variables. In the actual solution of the extremum problem electronic machine - aided analysis is imperative.

As has been mentioned earlier, the solution of the extremum problem does not yield a unique optimum combination of factors, but an infinite number of combinations which, from the point of view of production, are all optimum. This is the Pareto efficiency locus. The most desirable point of operation on the Pareto efficiency locus is determined by considerations of demand as described in the previous section.

(iii) Procedure for Arriving at Optimum Point

The existing structure of an economy may be expressed as a point in the multi-dimensional space of production sectors. In an underdeveloped Country, this point is bound to be far from the optimum surface. The remaining task of the program is to suggest possible methods for "moving" the operating point of the economy to a position on the optimum output surface. Of course, the approach is dynamic in the sense that the optimum surface itself is moving with time (as the production factors change).

In the process of examining the various possible methods of approaching the optimum point, it is essential that a study be made of the conditions which lead the economy to its initial low level. The knowledge of these conditions enable one to develop methods for eliminating them. The presence of monopolies causing the market prices to be dif-

ferent from the shadow prices; an inefficient technology with the inevitable waste of production factors; the existence of an in-appropriate fiscal policy; the lack of an industrial "leading sector" are but a few of the factors that may retard the advancement of a backward Nation.

It is clear that some of the points on the optimum surface will be more desirable or more accessible than others. In addition, to each point on the surface there corresponds a particular value of the demand function(Eq. 3). These two considerations, namely the position of the present point of the economy with respect to the optimum surface, and the demand function which is most desirable, should influence the selection of a particular optimum point. Since the selection of a most desirable demand function involves value judgements, this last part of the study is not scientific in the true sense of the word. Inevitably this part of the study should be performed in close consultation with the political leaders of the Country.

Once the desirable point has been decided upon and all the corresponding levels of the production and consumption factors have been noted, it is then possible to define these as the specific objectives of the program. For instance, which industries should be encouraged or how capital should be invested is decided by the comparison of the present distribution of the production factors associated with a particular production sector and the desirable optimum distribution.

Another factor which should be considered in the selection of the method of approach of the optimum operating point is the availability and rate of acquisition of foreign capital. This is necessary because foreign capital is essential to the advancement of under-developed countries and because it influences the dynamic behavior of the Pareto efficiency locus.

E. Scientific Personnel Needed in Implementing the Program

The large variety of specialists needed in the implementation of National Technical and Economic Development Programs is quite evident.

The economist and the social scientist play the most important role in the establishment of sectors and the collection of the field data. Other specialists such as engineers, geologists, agriculturists, etc. are also needed in this part of the study. The geologists, for example, will be called upon in the determination of the production factors related to some natural resources. The engineer, on the other hand, will examine, from the technical point of view, which combinations of production factors are feasible.

The implementation of the program leans quite heavily on the mathematician. His contribution in expressing the technological relations of production explicitly and in processing the equations to establish the Pareto efficiency locus, is clearly indispensible.

Finally, the social and political scientist and the technologist must cooperate closely when the questions of "most desired point" and "best procedure" for approaching it are brought up. The political and social scientist will be chiefly responsible for the selection of the most desired point, whereas the technologist must study the technical feasibility of any scheme, advise on the most efficient method of development of new industries, or invent new processes which are suited to the particular conditions of the land. Thus, the technologist will play a prominent role in the decision on methods of advancement.

4. THE SCIENTIST IN THE ADVANCEMENT OF NATIONS

The study of economic programs of the type described in the present communication reveals a new and important role of the scientist in the progress of humanity.

Since the early days of civilization the scientist has been a major contributor to the field of progress. His discoveries and inventions through the ages have given man ever greater facilities and comfort. In this respect the contribution of the scientist to the advancement of Countries is as old as civilization itself.

However, in an underdeveloped state, the invention of new processes and the design of new machines do not contribute immediately to the advancement of the Nation. In order that the invented machine may be built and used, the Country must already have reached a certain level in technology, education and available income; that is, a certain standard of living. The selection of the factors which may increase the standard of living has in the past been solely the responsibility of the political leaders of the Country. Planning for economic growth was formulated on the basis of experience and intuition. The role of the scientist in this field has been a secondary one. He often acted as advisor to the government in questions pertaining to development of particular industries but he was not given the opportunity to contribute his skills in the formulation of the basic structure of an economic program.

The present times have seen the growth of two great movements of history: the scientific and technological revolution on the one hand and the advancement of new and underdeveloped Nations on the other. The persons associated with one of the great movements have been different from those responsible for the other. The connection between their work has been only indirect.

It is believed that the scientist has the responsibility to link his work more closely with that of the persons concerned with the emancipation of new States or the advancement of Countries under development. The methodology for economic programs suggested in this paper aims exactly at this proposition. What is referred to as "scientific approach to technical and economic development programs" constitutes a unique example in which individuals responsible for the two great movements of our times can join forces for the benefit of mankind.

LIST OF REFERENCES

1. Bellman, R., "Dynamic Programming" Princeton University Press, 1958.
2. Dorfman, R., P. A. Samuelson, and R. M. Solow, "Linear Programming and Economic Analysis" McGraw-Hill, 1958.
3. Hildebrand, F. B., "Methods of Applied Mathematics" Prentice-Hall Inc., 1956.
4. Lewis, W. A., "Principles of Economic Planning" London, 1949.
5. Lewis, W. A., "Theory of Economic Growth" London, 1955.
6. Rosenstein-Rodan, P. N., "Industrialization of Eastern and Southeastern Europe" Economic Journal, 1943.
7. Samuelson, P. A., "Foundations of Economic Analysis" Harvard University Press, 1955.
8. Samuelson & Solow, "A Complete Capital Model with Heterogeneous Commodities" Quart. Jrnl. of Economics, 1956.
9. Scitovsky, T., "Two Concepts of External Economics" Journal of Polical Economy, 1954.
10. Solow, R. M., "A Contribution to the Theory of Economic Growth" John Hopkins Press, 1958.

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