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A Macroeconomic Prediction Model for the Development of Research Capacity During 1971—1980

The prediction for the development of science and technology is one of the basic constituents of the prediction system for the socio-economic development in Romania.

The present development of society is marked by an ever growing importance of science within the process of expanded reproduction. Nowadays most countries agree to the idea that the scientific potential determines the growth dynamics of the entire economy. In this context, the prediction for the development of science acquires particular importance.

The funds assigned in Romania for developing and financing the material foundation of science will amount to 15,600 million lei during 1971—1975 — that is more than twice as against the allocations during the previous five — year period — and the number of research workers in 1975 will be about 27 per cent larger than in 1970.

Therefore, the complex prediction system concerning the directions of scientific development, as a constituent part of the whole prediction system of Romanian socio-economic development must lay bare the development of the complex process of materialization of the technical and scientific creation, from the forecasting of the main ideas to appear up to their industrial assimilation under an ever growing efficiency.

As professor Manea Mănescu points out*), "The economic and social changes taking place in the world at present render ever more necessary the working out of long-range development prediction theories, the prediction

*) Manea Mănescu: *An Economic and Social Development Prediction for Socialist Romania*, "Viitorul social", No. 1, 1972.

of economic and social phenomena that have become so quick and complex, in view of substantiating the decisions of economic policies".

On analyzing the problems related to the development predication and strategies for Romanian scientific research, the authors have reached the conclusion that it is essential to draw up a pile of cybernetic and economic models closely interconnected.

Fig. 1 offers a general view of such models, the manner in which they mutually supply information to each other, the way in which the output data of some of them become the input data (restrictions) of some others.

Taking into account the questions to be answered, we have concluded that it is necessary to draw up and solve the following big types of models:

a) Aggregate macroeconomic models for correlating the scientific research development with the general economic growth in the Socialist Republic of Romania. The authors understand such models to be similar to the economic growth models, with the only difference that the branch of science stands out distinctly. These models shall underlie prediction for the development of the proportion of expenses assigned for research within the entire national income (or the final social product), as well as for the research staff within total labour.

Since prediction for science development is an essential constituent part of general prediction for socio-economic development, such models shall ensure the connection between the general development of economy and the general development of science.

On the basis of this very class of models the efficiency of scientific research shall be ascertained, considering its contribution to the national income.

Here, we shall only outline such a type of model, whereas its full description, qualitative properties and calculus algorithmus will be given in subsequent papers.

First of all, we are to specify that, to our seeming, such dynamic models for economic growth shall contain discrete variables, since these better illustrate the economic phenomena and developments. *)

Denoting by Y_n the final social product created at moment n, we shall assume this to be a function of four variables: the amount of labour existing in economy L_n; the amount of fixed funds (as a rule, only the productive fixed funds shall be considered) K_n; the technological level attained in economy T_n; and the time factor n that stands for the general influence of the technical progress on the economic growth.

As a rule, as pointed out, we mark a distinction between the technological level attained T_n and the time factor n.

So:

$$Y_n = F(L_n,\ K_n,\ T_n,\ n)$$

or, in a simpler form:

$$Y_n = F_n\ (L_n, K_n,\ T_n),\ n = 1,\ 2, \ldots,\ N$$

*) Manea Mănescu: *Economic Mathematical Modelling*, "Economic Computation and Economic Cybernetics Studies and Research", No. 3, 1970.

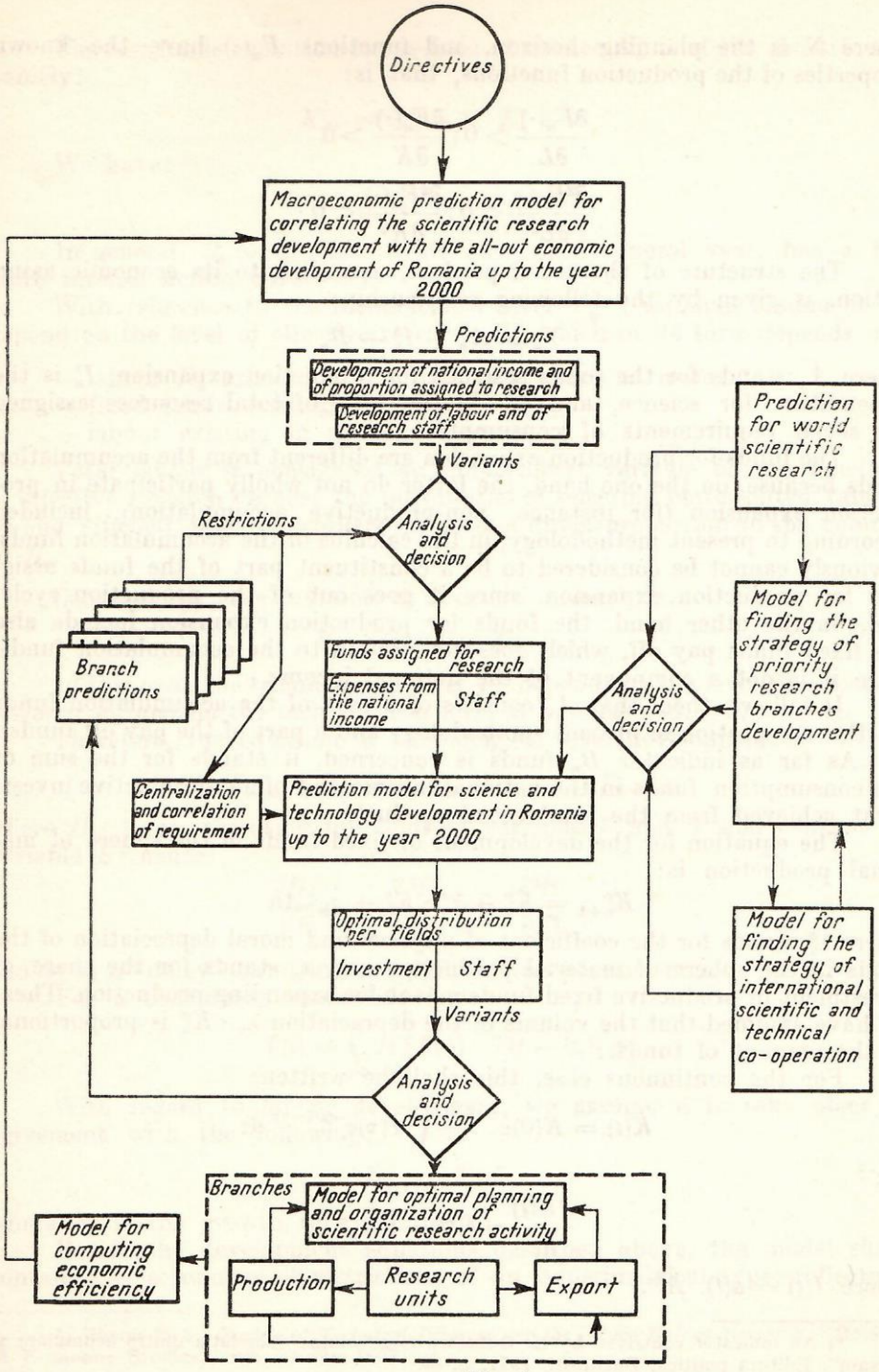
Directives
Macroeconomic prediction model for correlating the scientific research development with the all-out economic development of Romania up to the year 2000
Predictions
Development of national income and of proportion assigned to research
Development of labour and of research staff
Variants
Restrictions
Analysis and decision
Branch predictions
Funds assigned for research
Expenses from the national income
Staff
Centralization and correlation of requirement
Prediction model for science and technology development in Romania up to the year 2000
Optimal distribution per fields
Investment
Staff
Variants
Analysis and decision
Prediction for world scientific research
Model for finding the strategy of priority research branches development
Analysis and decision
Model for finding the strategy of international scientific and technical co-operation
Branches
Model for optimal planning and organization of scientific research activity
Production
Research units
Export
Model for computing economic efficiency

Fig. 1

where N is the planning horizon, and functions $F_n(\cdot)$ have the known properties of the production functions, that is:

$$\frac{\partial F_n(\cdot)}{\partial L} > 0; \frac{\partial F_n(\cdot)}{\partial K} > 0$$

$$\frac{\partial^2 F_n(\cdot)}{\partial L^2} < 0; \frac{\partial^2 F_n(\cdot)}{\partial K^2} < 0$$

The structure of the social product, according to its economic assignation, is given by the following relationship:

$$Y_n = A_n + I_n^s + B_n$$

where A_n stands for the funds assigned for production expansion, I_n^s is the expenditure for science, and B_n is the level of total resources assigned for social requirements of consumption.

The funds for production expansion are different from the accumulation funds because, on the one hand, the latter do not wholly participate in production expansion (for instance, non-productive accumulation), included according to present methodology, in the calculus of the accumulation funds, obviously cannot be considered to be a constituent part of the funds assigned for production expansion, since it goes out of the production cycle) and, on the other hand, the funds for production expansion include also the fixed funds pay off, which does not pertain to the accumulation funds, since it is not a component of the national income.

It follows, then, that A_n consists of a part of the accumulation funds (in the acceptation of present methodology and a part of the pay off funds).

As far as indicator B_n funds is concerned, it stands for the sum of the consumption funds in the national income and of non-productive investment achieved from the total social product.

The equation for the development of fixed funds in the sphere of material production is:

$$K_{n+1}^p = K_n^p - \lambda_n^p \cdot K_n^p + a_n \cdot An$$

where λ_n^p stands for the coefficient of physical and moral depreciation of the funds in the sphere of material production and a_n stands for the share of investment in productive fixed funds meant for expanding production. Then, we have assumed that the volume of the depreciation $\lambda_n \cdot K_n^p$ is proportional to the amount of funds.

For the continuous case, this shall be written:

$$K(t) = K(0)e^{-\lambda t} + \int_0^t I(\tau)e^{-\mu(t-\tau)}\, d\tau$$

or:

$$\frac{dK(t)}{dt} = I(t) - \mu K(t).$$

where $I(t) = a(t).\ A^{(t)}$.

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*) An indicator contrived by E. Dobrescu (see volume "Corelația dintre acumulare și consum", Editura politică, București, 1971, p. 89.

The law funds evolution in the field of science K_n^s is of the same form, namely:

$$K_{n+1}^s = K_n^s - \lambda_n^s K_n^s + I_n^s$$

We have:

$$K_n = K_n^p + K_n^s$$

In general, $\lambda_n^s \gg \lambda_n^p$, since wear, particularly moral wear, has a far more intense action in science.

With reference to the technological level T_n*), we shall assume it to depend on the level of effective research E_n, which in its turn depends on:

— labour R_n existing in the field of research at moment n;
— fixed funds existing in this field K_n^s;
— labour existing in national economy L_n.

Total labour is considered an independent variable of the function of effective research because the possibilities of selecting better gifted, talented and efficient research workers increase in direct proportion to the volume of L_n.

Consequently, the function of effective research is:

$$E_n = G_n (R_n, K_n^s, L_n)$$

In this case, the technological level T_n depends on the level of effective research E_n and on the technological level at moment n-1, n-2, ..., n-θ_n.

Therefore, the equation of technological level development is:

$$T_{n+1} = H_n (E_n, T_n, T_{n-1}, \ldots T_{n-\theta_n})$$

where $H_n(\cdot)$ are increasing functions in variables E and T and concave in variable E; hence:

$$\frac{\partial H_n}{\partial E} > 0; \frac{\partial H_n}{\partial T} > 0; \frac{\partial^2 H}{\partial E^2} < 0$$

and θ_n is a "delay" occurring naturally in the phenomenon.

For a continuous model we have:

$$T(t) = \int_0^t H [E(\tau), T(t - \theta_\tau)] \, d\tau$$

With regard to labour development, we assume it to take place in agreement with the following:

$$L_{n+1} = \delta_n L_n$$

where δ_n is the growth rate of labour.

Beside the development equations described above, the model shall contain also a number of restrictions of an isoperimetrical type, reflecting

*) Phelps E. S.: *Models of Technical Progress and the Golden Rule of Research*, "Review of Economic Studies", vol. 33 (2), 1967.

the correlative restrictions which occur as a result of the concrete circumstances under which prediction is carried on, as well as an objective—function reflecting the optimum macroeconomic criterion that has been chosen.

With the aid of such a prediction model for long-term economic growth one can find the development of the optimal values of the control parameters of the model, namely:

— the rate of accumulation: $U_n = \frac{Q_n}{Y_n}$, where we have denoted $Q_n = A_n + I_n^s$;

— the rate of accumulation in funds assigned for research:

$$V_n = \frac{I_n^s}{Q_n}$$

— the proportion of labour in the field of research, as against total labour:

$$Z_n = \frac{R_n}{L_n}$$

In carrying out such a model, a number of very complex problems arise in connection with the working out of the functions involved in the model, as well as with the qualitative surveys, algorithms and computation programmes, etc. As a rule, the algorithms are grounded on the results achieved in the optimal systems theory, especially Pontryagin's maximum principle and its subsequent generalizations.

A particular part in using such models is played by the qualitative survey, according to which a number of conclusions as to the simulation possibilities of different prediction variants can be drawn.

The results achieved with the aid of such models make up the input data of the dynamic model which is to underlie the prediction for the optimal configuration of Romanian science and technology in each stage. In fact, these results become restrictions of the model.

b) Another class of models of the system contains the models worked out in view of *predicting the general development of science on a world scale.* In such models, one shall make use of all available information related to predictions drawn up in other countries, alongside with an inquiry — a Delphi type investigation — of large numbers of experts in all the fields of science and production.

Such models shall enable predictions concerning the branches of science to become of particular importance, the branches to spring up in the future; the fields of application of new inventions and discoveries shall also be ascertained.

c) *Models for ascertaining strategy in view of developing some priority fields of Romanian science.* With the aid of the information achieved through the prediction models described in b), and turning to account the traditions of and the potential to be attained by Romanian science, it will be necessary to predict the priority fields in which Romanian science is to develop.

From the standpoint of economic cybernetics, we think that such models shall pertain to the class of dynamic games, in which one of the partners is Romanian science, and the other partner is science of other countries.

d) In case we consider the prediction models under the form of some co-operation dynamic games, we shall be able to draw up a number of predictions with regard to the possibilities and advantages of co-operating with other countries in certain fields.

As we can see in Fig. 1, the models described both at point c) and point d) provide information (input data — restrictions) for the model underlying *the optimal configuration of Romanian science and technology.*

e) *Econometric models of prediction for the development of scientific research requirements in each branch of national economy.* With the aid of prediction models for the development of branches and sub-branches of national economy, the minimal and maximal limits of the requirement for scientific research labour in each branch and sub-branch of national economy shall be ascertained.

Through a previous deep-going economic analysis the main factors which determine the research capacity development in each branch have been found out.

Such elements, contingent upon the peculiarities of each branch, are: the production dynamics, the investment dynamics (out of which: investment for new technologies of an original conception), the new products dynamics (out of which: new products of an original conception), the labour dynamics, the labour productivity dynamics a.s.o.

The prediction models underlying the minimal and maximal limits of the requirement for scientific research labour in each branch are models of an econometric type.

By working out multiple regression equations concerning the relationship between the development of these indicators and the requirement for scientific research labour, it is possible to find also the intensity of the influence exerted by the latter on the size of each such indicators.

It is obvious that these prediction models must be improved with the aid of factorial analysis, stochastic processes theory (particularly Markov's chains), etc.

f) *Dynamic models of prediction for science and technology development in Romania.* Such models underlie the prediction for the development of an optimal distribution of necessary research staff and investment per fields and branches.

We stress once more that the conception of working out such models is a unitary cybernetic conception, so that among all the types of models, a permanent information flow will exist, and the alteration of an element in one of the models will enable the automatic correction of the whole system of results. It goes without saying that all this means that the system of models, the programmes worked out and the results obtained shall be stored on magnetic carriers, in form of record cards that shall be continuously updated and improved.

We further describe the conception of the prediction model for the development of research capacity in Romania during 1971—1980, as well as a number of concrete results achieved in agreement with this model.

The main functions of the model have as an object the optimization of the resources *) distribution per potential consumers.

Based on the models described at point e), we assume to be known these consumers' previous development, as reflected by various indicators.

For each prediction element, the restrictions shall be generated by the situation that serves as a starting point, the stage attained when the prediction has been drawn and the set of values determined by the probable developments at the ultimate level of prediction, or at various intervals within this field.

We understand to have a similar diagram for each prediction element and field, and with its aid we shall find the space of admissible solutions. It is obvious that, for more complex circumstances, the space of admissible solutions appears to be an intersection of the spaces pertaining to each prediction element.

The model contemplates the use of several prediction techniques for the correlated factors. In our opinion, this is of particular practical importance for, given the generally distinct nature of the resources (investment means, labour of different skill, etc.), distinct exploring techniques are required.

The stages envisaged for drawing up the model are as follows:

Stage I

Ascertaining the resources.

The model shall contain a number whatever of resources:

$$R_1,\ R_2 \ldots R_k$$

in variants:

$$R_1 : R_{11},\ R_{12}, \ldots R_{1p1}$$

$$R_2 : R_{21},\ R_{22}, \ldots, R_{2;\,p2}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots$$

$$R_k :\ R_{k1},\ R_{k2}\ , \ldots\ R_{k\,p_k}$$

Likewise, the development prediction for each resource may be drawn up in different variants, obtaining distinct levels for the last year of the prediction horizon or for diverse intermediate years.

Stage II:

Ascertaining the probable consumption and prediction elements.

As soon as the resources and the probable development laws have been found, it is possible to point out the prediction objectives **)

*) The term resource, used in a broader meaning, refers to humman, material, financial, etc. resources.

**) As far as the order of the two stages is concerned, it is often possible and necessary to reverse them, contingent upon the manner of approaching the topic.

The fundamental question to be answered through prediction concerns the ascertainment of the optimal manner of using the available resources so as to ensure a *maximal economic and social efficiency*. The introduction of the concept of optimization, in relationship with the criterion of economic and social efficiency involves, of course, the knowledge of the major options of economy and, consequently, when starting the drawing up of the model, we assume to have covered the stage during which the main directions in economy are ascertained.

As a consequence of these directions and taking into account certain technical aspects, the main consumers of resources can be ascertained. First of all, considering the general directions, it is possible to point out the general criteria and, respectively, the priorities in their distribution, for certain resources of a general use, such as labour.

In general, from the cybernetic point of view, we can assume within some system S to have always a number of resource consumers sub-systems.

Consequently:

$$S_1 \cup S_2 \cup \ldots \cup S_q \subseteq S$$

where consumption at moment n per sub-system is:

$$\begin{aligned} &S_1 \to \tau_{11}^n; \quad S_2 \to \tau_{12}^n; \quad \ldots\ldots\ldots \quad S_q \to \tau_{1q}^n \\ &S_1 \to \tau_{21}^n; \quad S_2 \to \tau_{22}^n; \quad \ldots\ldots\ldots \quad S_q \to \tau_{2q}^n \\ &S_1 \to \tau_{k1}^n; \quad S_2 \to \tau_{k2}^n; \quad \ldots\ldots\ldots \quad S_q \to \tau_{kq}^n \end{aligned}$$

The balance relationships:

$$R_i^n = \sum_{e=1}^{q} \tau_{ie}^n \qquad \begin{matrix} i = 1, 2, \ldots k \\ n = 1, 2, \ldots N \end{matrix}$$

are satisfied. (N is the size of the planning horizon).

We assume now to have the following relationship between consumption in each resource i (the input) and the output of the sub-system:

$$\tau_{ie}^n = \alpha_{ie}^n X_e^n \qquad \begin{matrix} i = 1, 2, \ldots\ldots k \\ e = 1, 2, \ldots\ldots q \\ n = 0, 1, 2, \ldots\ldots N \end{matrix}$$

where X_e^n is the size of the prediction element (the output of sub-system S_k) at moment n.

In agreement with this principle, we have the following matrix of unitary intensities:

$$\mathcal{A}^n = \| \alpha_{ie}^n \|_{kxq} \qquad n = 0, 1, 2, \ldots N$$

We specify that elements α_{ie}^n of structure matrix $\mathcal{A}^n$ are prediction objectives which are ascertained with the aid of econometric models.

It is obvious that elements α_{ie}^n may not depend on (time) index n but in the general case they are time functions. Therefore, when considering a

continuous variation of time we have in fact a functional matrix of the form:

$$\mathcal{A}(t) = \| \alpha_{ie}(t) \|_{kxq}$$

Reasonings related to the technical progress development lead to the conclusion that functions $\alpha_{ie}(t)$ are monotonically decreasing. Consequently:

$$\frac{d\alpha_{ie}(t)}{dt} \leqslant 0$$

Stage III

Ascertaining the optimal criteria.

This stage has a decisive bearing on the modelling process.

We shall remark, from the very beginning, that the optimization process is to be achieved for the entire system, and the restrictions imposed to each sub-system will result from the objectives aimed at with the all-out optimal working of the macrosystem.

The optimal criterion shall be found through a previous analysis, solidly substantiated from the standpoint of the State general economic policy.

This is all the more required since the optimal trajectories of the system development are, as a rule, particularly sensible in relation to the optimal criterion that has been chosen.

Specialists in modelling shall henceforth be highly concerned in drawing up models fit to an optimization of the economic phenomenon in relation to several criteria. This is of particular importance for our economy where, beside economic criteria, social factors pertaining to the responsibility of leading mechanisms are involved. In general, we can assert that, beside some fundamental objectives, we shall always have also objectives of a lesser importance, which cannot yet be overlooked. Therefore, it is generally necessary to make use of aggregate objective-functions.

Here we have to stress that, in our opinion, more importance is to be attached in the next to the optimization techniques in agreement with several criteria. The qualitative survey of the model, the investigation of the sensitivity of optimal trajectories in relation to different optimal criteria, and the finding of invariant trajectories in relation to the optimal criterion make up an important direction of focussing the problem.

Further, we describe the concrete way of applying the aforesaid concepts to the prediction model for the research capacity development during 1971—1980.

Working Hypotheses

In order to draw up the model we have considered the following working hypotheses:

1. Starting from Romanian experience and taking into account the situation existing in other countries, it has been assumed that *the scientific national potential can adequately be expressed through the number of highly qualified staff carrying out scientific research work.*

Analyses carried through have laid bare that, owing to the diversity of the research activity, a measurement of the scientific potential by "the

number of research workers'' or "total number of wage earners" is not expressive at present.

2. It has been necessary to make an adequate investigation, contingent upon the characteristic features of each field of science, regarding the proportion of highly qualified staff and other personnel concerned with research activities, as well as the number of highly qualified staff and *the degree of provision with fixed funds, particularly with apparatus.*

The following hypotheses have been assumed as regards the *restrictions* related to the way of development of certain branches:

3. The research capacity in each branch of national economy shall be developed in agreement with the assignments laid down in the Directives of the 10th Congress of the Romanian Communist Party, the priority research programmes, the surveys carried out recently in order to improve the five-year plan, as well as other assignments confided on the respective field of activity.

4. The increase in the research activity shall be achieved in a per branch differentiated manner, depending on the properties they have got within the general programme of development of national economy.

5. A two or three times increase in the total number of highly qualified staff, as against their number in 1970, shall be achieved in the priority branches of national economy before the end of 1975.

When adopting these working hypotheses, attention was paid to the situation existing on a world scale, where the annual increase rate in the number of research staff is of 7—12 per cent, so that during the last decades the number of research staff doubled in about 6—10 years. In this respect, the number of research workers in Western Europe and in United States increases twice each 10—15 years, and in U.S.S.R. twice each 7—8 years. The annual mean increase rate per total of personnel employed in research activities during these last years has been 6—7 per cent in Hungary, 9—11 per cent in U.S.S.R and approximately 11 per cent in France.

6. Each highly qualified wage earner shall be provided with a certain amount of fixed funds, particularly with apparatus, as well as with assistance personnel (middle-school employees and workers), so ensuring adequate conditions and employment for the creative capacity of the highly qualified staff.

To this end, a per branch differentiated ratio between total research personnel and highly qualified research workers has been considered up to 1975; this ratio varies from 1.3 to 5.0, and it was correlated with the suggestions advanced by the ministries and included in the staff training programme for 1971—1980.

7. The prediction has been worked out for 24 branches.

Description of the Mathematical Model

After every technical and economic aspect of the problem has been cleared up, a mathematical model is worked out. In broad lines we discern here three essential moments:

— Ascertaining the unknowns of the problem;

— Working out the restrictions;
— Drawing up the objective-function.

The unknowns of the problem, in agreement with working hypothesis No. 1, are:

X_i^n stands for the number of highly qualified wage earners in branch i, in the year n

$$i = 1,2,\ldots\ldots\ldots, 24$$
$$n = 1975,\ 1980$$

Consequently, for the two prediction levels we have 48 unkowns in all.

Restrictions

Restriction 1. The total number of research wage earners on a national economy scale shall not exceed a level S, ascertained in an exogene manner. This level interfering in the model as a restriction is an output of the economic growth model as described at point a).

For the concrete case under examination, the following variants have been considered:

	1975	1980
Variant 1	$S_1 = 55{,}000$	$S_1 = 110{,}000$
Variant 2	$S_2 = 60{,}000$	$S_2 = 120{,}000$
Variant 3	$S_3 = 64{,}700$	$S_3 = 129{,}400$
Variant 4	$S_4 = 70{,}000$	$S_4 = 140{,}000$

Consequently:

$$\sum_{i=1}^{24} \alpha_i^n X_{ik}^n \leqslant S_k^n \qquad \begin{matrix} n = 1975,\ 1980 \\ k = 1,\ 2,\ 3,\ 4 \end{matrix}$$

where α_i^n is the total number of research wage earners as against one highly qualified research worker in branch i, and

$$\alpha_i^{1975} = \alpha_i^{1980}$$

We specify that the very element α_i^n is a prediction element.

Restriction 2. Total investment for science shall not exceed level I, as ascertained in an exogene manner; this restriction shall represent an output of the economic growth model.

Solutions have been simulated in agreement with the following variants:

	1975	1980
Variant 1	$I_1 = 3{,}500$ million lei	$I_1 = 7{,}700$ million lei.
Variant 2	$I_2 = 3{,}800$ million lei	$I_2 = 8{,}400$ million lei.
Variant 3	$I_3 = 4{,}000$ million lei	$I_3 = 8{,}800$ million lei.
Variant 4	$I_4 = 4{,}500$ million lei	$I_4 = 9{,}900$ million lei
Variant 5	$I_5 = 4{,}800$ million lei.	$I_5 = 10{,}600$ million lei.

Consequently, we have restriction:

$$\sum_{i=1}^{24} \beta_i^n X_{ik}^n \leqslant I_k^n \qquad \begin{matrix} n = 1975,\ 1980 \\ k = 1,\ 2, \ldots, 5 \end{matrix}$$

where β_i^n is the investment per highly qualified research worker in branch i.

One of the restrictions taken into account when predicting values β_i has been the provision for a technical equipment increase in 10 per cent of fixed funds per highly qualified research worker in 1975 as against 1970. Likewise, based on some predictive calculations, it has been estimated that

$$\beta_i^{1980} = 1 \cdot 3\, \beta_i^{1975}$$

Restriction 3. Investment in apparatus shall represent at least level I_1^n.

The simulation variants of solutions have been similar to those for restriction 2, where

$$I_{1,k}^n = 0.6\ I_k^n \ (k = 1,2, \ldots, 5;\ n = 1975,\ 1980)$$

was assumed.

We have the following restrictions:

$$I_{1k}^n \leqslant \sum_{i=1}^{24} \gamma_i^n X_{ik}^n \leqslant I_k^n \qquad \begin{matrix} n = 1975,\ 1980 \\ k = 1, 2, \ldots,\ 5 \end{matrix}$$

where: γ_i^n is the investement in apparatus per highly qualified research worker in branch i.

When working out prediction for indicators γ_i also has been taken into account the provision for an increase in at least 0.20 per cent of apparatus equipment per higly qualified research worker as against the year 1970.

We have:

$$\gamma_i^{1980} = 1.4\, \gamma^{1975}$$

Restriction 4. The research equipment with import devices shall be effected within the limits of the fund assigned for this purpose: V^n

The following variants have been considered:

$$\text{Variant 1: } V_{1,k}^n = 0.5\ \ I_{1,k}^n \qquad n = 1975,\ 1980$$

$$\text{Variant 2: } V_{2,k}^n = 0.65\ I_{1,k}^n \qquad k = 1, 2, \ldots, 5$$

The restriction is:

$$\sum_{i=1}^{24} \delta_i^n X_{ik}^n \leqslant V_{ek} \qquad \begin{matrix} n = 1975,\ 1980 \\ e = 1, 2;\ k = 1, 2 \ldots, 5 \end{matrix}$$

where: δ_i^n is the equipment with imported devices per highly qualified research worker in branch i.

We have the following variants:

$$\delta_i^{1980} = 2\delta_i^{1975}$$

$$\delta_i^{1980} = 1.5\delta_i^{1975}$$

$$V^{1980} = 4V^{i975}$$

Restriction 5. These restrictions concern the minimal (respectively maximal) level to be attained (respectively not to be exceeded) by scientific research in each branch.

Consequently:

$$A_i^n \leqslant x_i^n \leqslant B_i^n \qquad \begin{matrix} i = 1, 2 \ldots, 24 \\ n = 1975,\ 1980 \end{matrix}$$

Values A_i^n and B_i^n have been found with the aid of prediction models similar to those described at point e).

We stress that a most accurate ascertainment of these two levels is of particular importance, for they play an essential part in finding the space within which solutions can be simulated. As a rule, the most frequent situations in which these values have been found in different variants have been:

For the year 1975:

$$E^{1970} \leqslant A_i^{1975}$$

$$1.1\,E^{1970} \leqslant B_i^{1975} \leqslant 3\,E^{1970}$$

where: E^{1970} stands for the existing staff at the level of the year 1970.

Objective-Functions

For this mathematical model several types of objective-functions have been considered, taking into account various economic criteria, as well as a number of aggregate objective-functions.

Objective-function I. The branches of national economy whose activity *(production)* increases more quickly have a priority in the assignment of scientific research staff.

Consequently, the objective-function is:

$$max \sum_{i=1}^{24} p_i^n X_i^n \qquad n = 1975,\ 1980$$

where p_i^{1975} is the production increase of branch i as against 1970; and p_i^{1980} has a similar meaning.

Objective-function II. The branches of national economy developing more quickly (involving higher *investments*) have a priority in the assignment of scientific research staff.

Consequently:

$$max \sum_{i=1}^{2} q_i^n X_i^n \qquad n = 1975, 1980$$

where q_i is the absolute value in units of the investment.

Objective-function III. The branches of national economy in which *new products*, made on the basis of an original national conception, attain higher values, have a priority in the assignment of scientific research staff.

Consequently:

$$max \sum_{i=1}^{24} \lambda_i^n X_i^n \qquad n = 1975, 1980$$

where λ_i is the absolute value in units (thousands of lei) of the new products made during the five-year period.

Objective-function IV. The branches of national economy in which the *total number of wage earners* has a higher proportion have a priority in the assignment of scientific research staff.

Consequently:

$$max \sum_{i=1}^{24} r_i^n X_i^n = n = 1975, 1980$$

where r_i^{1975} is the wage earners' growth index in 1975 as against 1960. r_1^{1980} has a similar meaning.

Objective-function V. The branches of national economy in which *productivity* must increase at quicker rates have a priority in the assignment of scientific research staff.

Consequently:

$$max \sum_{i=1}^{24} t_i^n X_i^n \qquad n = 1975, 1980$$

where t_i^{1975} is the labour productivity growth index at the level of the year 1975 as against 1970, and t_i^{1980} has a similar meaning.

Objective-function VI. The branches of national economy in which commodity-output *expenses per 1,000 lei* must fall down more sharply have a priority in the assignment of scientific reserach staff.

Consequently:

$$min \sum_{i=1}^{24} Z_i^n X_i^n \qquad n = 1975, 1980$$

where Z_i^{1975} is the absolute value (in lei) of the expenses made per 1,000 lei of commodity-output at the level of the year 1975, and Z_i^{1980} has a similar meaning.

Beside the solutions reached on the basis of these objective-functions, a number of solutions making use of aggregate objective-functions of the form:

$$max \sum_{j=1}^{6} C_j F_j$$

have also been simulated, writing $F_1, \ldots, F_6$ for the objective-functions, described above, whereas proportions C_j have been ascertained, in different variants, based on some inquiries carried out among specialists in various fields and organizations.

As an illustration, we give further three estimation variants for such proportions.

PROPORTIONS OF THE OBJECTIVE-FUNCTIONS

	I	II	III
1. Gross output	0.5	0.7	0.8
2. Investment in agreement with new technologies of an original national conception	0.3	0.9	1.0
3. New products made in agreement with an original national conception	0.2	0.9	1.0
4. Total number of wage earners per central body	0.6	1.0	0.7
5. Labour productivity	0.1	0.8	0.8
6. Expenses per 1,000 lei of commodity-output	0.4	0.5	0.7

All this clearly illustrates the tremendous number of variants in which the model has been worked out. In order to shorten the performance time on the computer, a L.P.S (Linear Programming System of the I.B.M. programs library at the Computation Centre of the Economic Cybernetics Department, the Academy of Economic Studies has been used to simulate the different prediction variants.

All the details of the problem, the different variants for the model parameters, as well as the optimal solution are stored on magnetic disks in index cards that can be permanently analyzed. When considering a new variant, this shall be computed starting from the older optimal variant by updating it, without resuming the whole operation from the very beginning.

A particular advantage offered by the L.P.S program is related to the variety and abundance of information provided by the post-optimal linear programming analysis, which is obtained by request.

This post-optimal analysis enables a through investigation in the behaviour of the solution around the optimal point when some of the para-

meters of the problem are altered, as well as an ascertainment of the variation limits of these parameters, on condition that the optimal solution is not altered.

Conclusions

By solving the models described in this paper, valuable information regarding the trends of scientific research capacity development during 1971—1980 has been obtained. The experience accumulated so far has once more stressed the efficiency that can be achieved by making use of economic cybernetic methods and of computation techniques in working out long-term predictions. Likewise, it has become conspicuous the necessity of simulating a great many variants, out of which the decision-making factors shall choose the most efficacious variants.

We have to add that with the aid of such models it was possible to substantiate at a higher level the provisions of the five-year plan concerning the research capacity growth, closely related to the assignments it has got in the framework of national economy growth.

Thus, on the basis of the suggested optimal solutions, an increase in about 180 per cent in the number of highly qualified research staff has been decided, as well as an investment amounting to 4,500 million lei, as against 1,700 million lei during the previous five-year period.

UN MODÈLE MACROÉCONOMIQUE CONCERNANT LE DÉVELOPPEMENT DE LA CAPACITÉ DE RECHERCHE DURANT LA PÉRIODE 1971—1980

La période contemporaine se caractérise par une importance toujours accrue de la science appliquée à l'entier processus de la reproduction élargie. Dans ce contexte, la prévision du développement scientifique a une importance toute particulière.

On énumère dans cet article des modèles cibernétiques-économiques nécessaires à être élaborés et résolus en vue de la prévision du développement de la science et de la technologie dans la R. S. de Roumanie. On présente aussi le procédé d'interconnexion de ces modèles, et la modalité de se fournir réciproquement les informations.

Dans la seconde partie de l'article les auteurs exposent un modèle concret, élaboré en vue de la prévision du développement de la science et de la technologie dans la R. S. de Roumanie durant la période 1971—1980.

On indique les étapes qui doivent être parcourues pour l'élaboration d'un tel modèle, les hypothèses de travail, ainsi que certaines conclusions concernant les résultats pratiques obtenus.

МАКРОЭКОНОМИЧЕСКАЯ МОДЕЛЬ РАЗВИТИЯ ИССЛЕДОВАТЕЛЬСКОЙ МОЩНОСТИ В ПЕРИОДЕ 1971—1980 гг.

Современный период характеризуется все возрастающим значением науки во всем процессе расширенного воспроизводства. В этой связи прогноз развития науки приобретает особое значение.

В настоящей статье приводится подлежащий разработке и решению комплекс необходимых экономико-кибернетических моделей для прогноза развития науки и технологии в Социалистической Республике Румынии. Указывается также способ увязки этих моделей и взаимного поставления информации.

Во второй части статьи авторы приводят разработанную конкретную модель для прогноза развития науки и технологии в Социалистической Республике Румынии в периоде 1971—1980 гг.

Указываются этапы, которые должны быть пройдены для разработки такой модели, рабочие гипотезы, лежащие в ее основе, и некоторые выводы о практически достигнутых результатах.