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Albegov, M.

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Murat Albegov

2361
Laxenburg
Austria
International Institute for Applied Systems Analysis

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Introduction

In the last 10-15 years much work devoted to the problem of regional economic modeling was fulfilled both in countries with planned economies and those with market economies. This work differs by the objectives, complexity, time horizons, and extent of interregional problem analysis, applied tools and so on. It seems that the time has come to start comparative analysis of this work with the main aim to generalize elaborated approaches to the solution of the whole problem and methods which are used to solve particular parts of it. As a result one or more systems of models with a more general--and as far as possible universal--description of a subsystem may be constructed.

The International Institute for Applied Systems Analysis (IIASA) seems to be the most appropriate place in which to try to organize this kind of exploration. Having the feasibility to organize an international team of scholars who represent different schools and directions of exploration, cooperating with the scientists from East and West, organizing international conferences and workshops, IIASA seems to be the natural center for this cooperative activity.

Undoubtedly, the activities might be fruitful only if cooperation with national institutions and other international organizations--the Regional Science Association is one of the first--is installed.

Nevertheless, several years of cooperative activity are needed to obtain the first practical results in order to achieve mutual understanding of the approaches and apparatus which correspond to the conditions in different countries.

Variations of Approaches and their Basis.

Contemporary IRD explorations are characterized by significantly diverse objectives and approaches. These variations in goals, tools, methods, etc. are reflected in a number of aspects which one tries to analyse more deeply and which are transformed correspondingly on the approaches to the problem. Among others, it is possible to mention the following items which usually determine the difference in approaches to IRD problem solution:

1. Size of region (territory) under analysis and a number of subregions within it.
2. Time horizon.
3. Detailedness of the results which are expected from the study.
4. Up-to-date development of regional economy (if it is a virgin or well-developed territory).
5. Method of regional analysis (simultaneously with other regions and national economy, or isolatedly), etc.

The first item is very important from the point of view of available results. For example, if one considers a region as one point, one can never solve the problems of pollution, location, human settlements, etc. But such types of models are convenient to obtain some features of macrocharacteristics of the region. Therefore the decision to analyse regions with problems using so-called "point-model" methods means there will be significant constraints of the possible results.

The choice of the time horizon plays an important role during the search for an adequate approach and appropriate mathematical tools.

To change something in regional development, to shift its economic structure, one needs five or more years. Usually the perspective from 5 to 20 years is analysed. Beyond 20 years the extent of uncertainty becomes so great that it is no longer possible to expect practical and meaningful results.

The duration of the period under observation determines the choice of the mathematical apparatus of regional problem analysis. For example, forecasting of regional long-term economy growth on the basis of econometric models, which are very successful for short-term analysis will undoubtedly be wrong.

The same may be said about the implementation of linear input-output balance for a long-term regional growth forecast. The through-time change in the matrix of the coefficient is so significant that the results of the calculations usually lose practical meaning.

The detailedness of the calculation results which are required by decision-makers or users of these studies generates a huge diversification of regional models. Depending on the specifics of the regional economy and on the users' request, one or several parts of the regional economics are described with the help of very sophisticated models when the other parts of the economy are in limbo. This approach is one of the sources of diversification of regional models.

It is impossible, of course, to unify the depth of analysis of separate problems in each model, but to attempt to generalize an existing experience, and to better understand the positive features of separate works seems to be a fruitful task.

Contemporary conditions of the regional economy has an important impact from the point of view of "openness" of future development. The more developed the region, the more influence its previous development has on its future growth. This influence is reflected qualitatively on such data as the technical coefficient of input-output tables, on the dimension of the agglomeration effect, and so on. The feasibility "to start from zero" in a common case simplifies the task substantially.

With reference to the fifth point, it is necessary to say that it deserves to be analyzed here in more detail.

Top-Down Approach Analysis

To obtain any practical results of regional analysis one needs information about the "outer conditions". This includes physical and/or economical information about flows of materials and products in and out of the region. So the question is how the "region" obtains this information: in the process of simultaneous analysis of all regions and the national economy or on the basis of isolated regional economy analysis, using the information of other explorations which were fulfilled at a different time and in different places.

If we try to analyze the problem with the help of a mathematical apparatus, the first approach means the consideration of the regional model as a satellite system to be attached in a consistent way into a system for the national economy as a whole.

This approach is very popular in countries with a planned economy (see, for example [1]) because it corresponds completely to the centralized scheme of the planning process of these countries.

One variant of such a system of models was proposed by the author during his work at the Council of the Location of Productive Forces (CLPF) under the Central Planning Committee of the U.S.S.R. [2]. The particularities of this variant (Figure 1) consist of the following:

a) Marginal costs of products and resources play an important role in this scheme.
b) The original method of coordination of sectorial and regional plans is proposed.
c) The scheme is oriented on a small number of iterations (with the aim of achieving results without unnecessary calculations).

This scheme is importantly dependent on the character of the function-marginal cost of resources / volume of its consumption. If this function has a linear or close to linear character then the correspondent resource may be included (Figure 1) into block 2, and if not, into block 3.

From the viewpoint of this approach all resources could conditionally be divided into two parts: global resources, and local resources. For "global" resources, the marginal costs per unit is practically constant and independent of any change in its consumption. As an example of the "global" resource one can take fuel, the price of which in any developed region of an industrialized country is practically independent of the volume of consumption. To generalize, it is possible to say that the more transportable the resource, the more basis it has to be counted as a global resource.

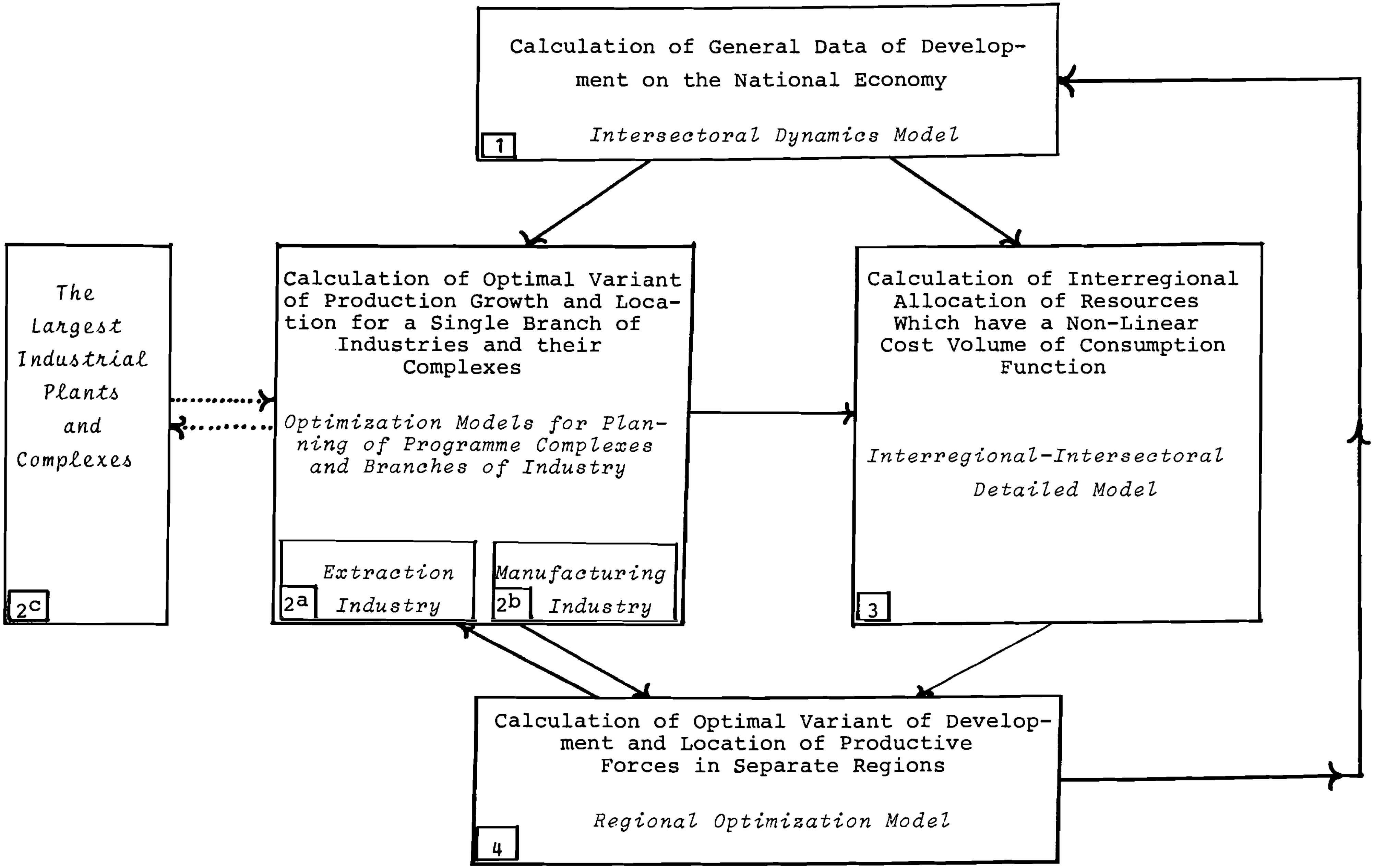


Figure 1. Sequence of Models for Territorial-Industrial Planning (CLPF-Variant)

As an example of "local" resources one could mention water. The possibilities of an interbasin, interregional watertransportation system are limited from the technical and especially the economical point of view. Therefore in the region with limited resources of water, the function cost/volume of consumption has evidently a non-linear character.

In block 2 of the proposed scheme there exists a sequence of analyses: from primary sectors to manufacturing and services. The main goal is to start from the parts of the national economy which are relatively independent, and for which a solution of otpmizing the problem provides a local optimum which is expected to be relatively close to the global one. A good example of this kind of resource is land. Therefore it is possible, for example, to begin fron the optimization of national agriculture with the aim of obtaining marginal costs of land. Experience shows that these marginal costs for rural areas are practically independent of the decision concerning the growth of other sectors of the national economy and of the location of its productive activities.

The obtained marginal costs of land may be taken into consideration during the analysis and modeling of primary industries, as for example in the case of fuel extraction and manufacturing industries. In the results of these kinds of approaches it is possible to obtain marginal costs of fuel which include the marginal costs of land. This approach allows the calculation on the first iteration of the results which are close to the final ones.

Study has shown that in order to obtain marginal costs it is not always necessary to use sophisticated models. For example, the system of marginal costs of fuel in the Soviet Union was obtained on the basis of the so-called "λ-task" of linear programming (Figure 2). The results closest to the aim were obtained with the help of more complicated models.

Alongside the numerical information, the qualitative information about the property of marginal costs has a very important significance. This knowledge allows one to construct a rough system of marginal costs if the calculations are not yet obtained, or to estimate the preciseness of those which are.

Primary Task

$$\sum_{ij} C_{ij} X_{ij} \longrightarrow \min$$

subject to:

$$\sum_{j} X_{ij} \leqslant A_i$$

$$\sum_{i} \lambda_{ij} X_{ij} = B_j$$

$$X_{ij} \geqslant 0$$

Dual Task

$$\sum_{j} \delta_j \nu_j - \sum_{i} a_i u_i \longrightarrow \max$$

subject to:

$$\lambda_{ij} \nu_j - u_i \leqslant C_{ij}$$

$$u_i \geqslant 0$$

Examples of Results of Calculations[1]

Region	Natural Gas	Oil	Hard Coal		Brown Coal from Kansk-Achinsk
			Out-of-mine	Sized	
1. Northwest	23-26	22-25	22-24	23-25	-
2. Komi SR	17-20	16-19	14-16	15-18	-
3. Northern Caucasus	21-23	20-22	20-22	21-23	-
4. Volga Basin	21-23	20-22	19-21	20-22	-
5. Southern Urals	19-21	17-20	15-17	16-19	-
6. Novosibirsk	15-18	14-17	10-13	12-14	8-10
7. Krasnoyarsk territory	-	15-17	10-12	12-13	2.5-3.5
8. Primorsk territory	-	19-21	16-18	17-19	-
9. Western Ukraine	23-26	22-25	21-23	22-24	-
10. Byelorussia, Lithuania	24-27	23-26	22-24	23-25	-
11. Georgia	21-24	20-23	21-23	22-24	-
12. Uzbekistan	15-17	14-16	14-16	15-18	-

Figure 2. Model for Fuel Marginal Cost Estimate and Various Results

[1]All calculations (per ton of coal equivalent) were completed before the energy crises, and now these estimates are higher.

A second important peculiarity of this scheme is the feasibility of coordinating a large dimension of tasks of sectoral and regional modeling. The general idea, then, is the following: it is better to lose somewhat in precision but to win in the dimension and have the possibility to analyse more supplementary regional problems. To realize this approach one does need to construct the special "reaction function" which shows the difference in the significance of the model's objective function when the variable under consideration changes step by step in significance from zero to the maximum (Figure 3).

Using this approach it is sometimes possible to cut short a dimension of a task which needs to be solved. For example, one industrial sector, the model of which includes more than one thousand equations, was described in the interregional intersectoral model (block 3 of Figure 1) with the help of thirty "reaction functions." The number of these functions correspond to the number of regions in the interregional intersectoral model.

It is important to emphasize also that all schemes are oriented on a minimum of iterations that must provide operability. In this scheme there are only two directions of coordination: during the analyses of structures of the largest industrial complexes and in the process of coordination of sectorial and regional plans.

In the former case this decision is related to the possible instability of sectoral marginal costs, dependent on a large complex structure and on location; in the latter, when the regions are analyzed consecutively, the final definition of the first regional structure makes the set of places of the location for the rest of the sectors much more restricted.

The botton-up approach seems very attractive for scholars who work in separate regions and for whom, naturally, the access to outer information is more or less restricted. They therefore try to base themselves on the "inner" kind of information and in only unavoidable instances do they include in their models variables or parameters which reflect external data.

Calculation of ΔF_{mn}

Let us suppose that we have the following non-linear task of the location of productive activities:

$$F = \sum_i [L_i(X_i)X_i + \sum_j (W_{ij}+S_j)Y_{ij}] \longrightarrow \min \qquad (1)$$

subject to:

$$\sum_j Y_{ij} = X_i \leq A_i \qquad (i = 1,2,\ldots,r,\ldots m) \text{ where } r \text{ is the point under consideration }, \qquad (2)$$

$$\sum_i \sigma_{ij} Y_{ij} = B_j \qquad (j = 1,2,\ldots,n) \; , \qquad (3)$$

$$X_i, \; Y_{ij} \geq 0 \qquad (i = 1,2,\ldots,r,\ldots, m; \; j = 1,2,\ldots,n) \qquad (4)$$

where X_i = dimension of production in point i and $\overline{X}^o = (X_1^o, X_2, \ldots, X_r^o, \ldots, X_n^o)$ and F^o corresponds to the optimal solution, then one must calculate F^* for $X_r = 0,\; 0{,}1A_r,\; 0{,}2A_r, \ldots, A_r$ and $Y = F^* - F^o$.

For the non-linear case it is possible to use $Y = f(Xr)$.

For the linear case it is possible to use $\Delta F_{mn} = \dfrac{\int^{A_r} Y(X_r)\,dX_r}{A_r}$.

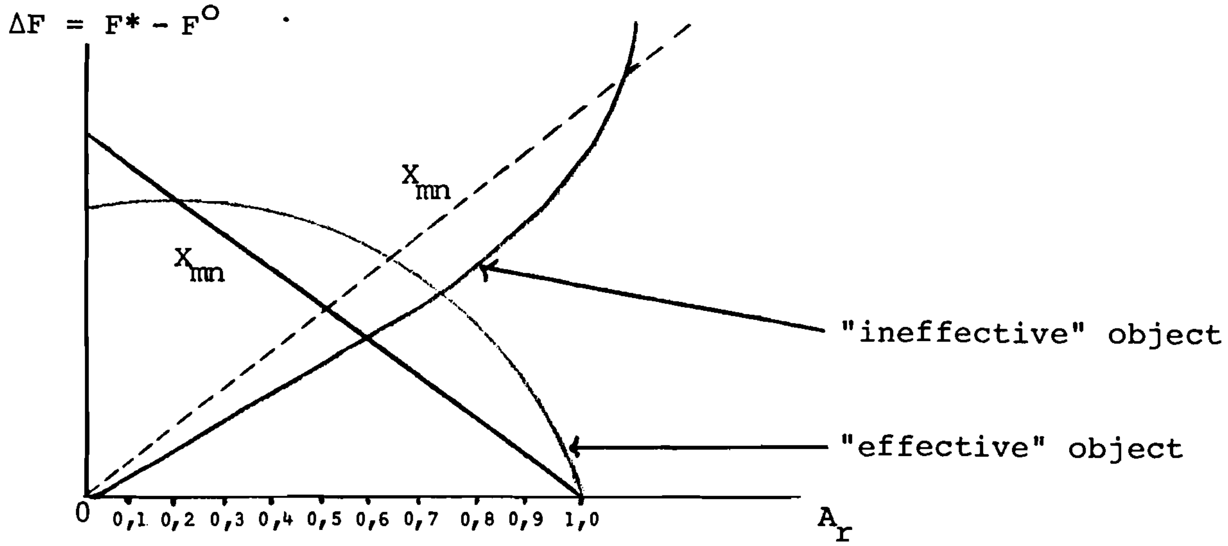


Figure 3. Calculation of Objective Function Coefficients

Bottom-up Approach

As it is shown in [3], countries with market economies use more often Economic Base, and Regional and Interregional input-output models. In the last decade, the Econometric approach also became very popular.

The essence of the economic base approach consists of sharing the regional economy in two parts: the production of basic (export) goods and non-basic goods (with the constant ratio of their production). Then as exogenous, one uses such kinds of data as regional export or investment, government expenditure and consumption, etc. It is obvious that the decision in this case is fully dependent on exogenous data. The latter, in turn, are calculated very roughly. For example, in [4] for the calculation of interregion shipment of goods alongside the optimization procedure, the author proposes three methods: the Export Production Method, the Import Use Method, and the Gravity Model Method. Analysis shows that these three methods have in common: they all use a hypothesis of stability in some relation, coefficients and so on, which were estimated for the base period. Therefore these approaches must be estimated as more or less sophisticated extrapolations of the past tendency into the future.

The implementation of input-output balance on a regional level has additional difficulties in comparison with its use for the whole country. The smaller the region the less stable the coefficients of the input-output matrix. Moreover, on the regional level it is necessary to analyse the intersectoral effect, the effect of agglomeration in different sectors of industry and economy in the context of industrial, agro-industrial and other complexes. Using input-output models, however, which are not related to a system of detailed industrial and other sectoral models, one is not provided with instruments which are adequate for the problem under analysis.

The usual implementation limits of the input-output technique was not mentioned above: the problem of substitution of technologies and products, the difficulties of final demand estimation (especially on the regional level) and so forth.

As L. Klein and N. Glickman write [5] in the past decade "no part of the world's economy escaped the specification-measurement-estimation-simulation routines that econometricians usually follow." As shown in [6] the U.S.A. situation is now close to those where each state has its own econometric model. At the same time, work may be fulfilled to related all these models with the help of one model which is analogous to the same kind of model as the "Link" model [7].

Regional econometric models are characterized by the detailedness of economic analysis. Practically all important sectors of the regional economy may be taken into consideration. This technique has, however, one important draw back: using as a basis data of regional development in the past, one could not expect precise calculation of long-term perspectives. Its implementation therefore to forecast future regional economical growth is very limited.

In the USSR, in some of the allience republics, the system of econometric models was elaborated [8]. In the Latvian system, as a starting point, the dynamic macroeconomic model is usually used. This model is based on a Cobb-Douglas function for estimating GNP. The main factors which determine regional GNP are the following: number of employed in the sphere of material production, capital investment and technological progress. The central model is supplemented by more detailed econometric and input-output models.

For this system of models a key problem is the organizing of minimum exchanges of information with other parts of the country and the attempt to forecast future regional economic growth on the basis of "inner" information. Undoubtedly this may be good alone only in the case when the character of ties with other regions of the country will, in the future, be the same as in the past or present. But in a common case the ties between regions usually change importantly through time.
As far as the regional econometric models constructed in only a few regions of the U.S.S.R., there was not attempt made to integrate them into one model.

One Possible Compromise

As was seen by the above mentioned, each approach from the two discussed earlier has its own negative points: for the top-down scheme it is very difficult to organize all regions and national level analysis simultaneously; for the bottom-up scheme, it is difficult to obtain outer information when the regional economy is analyzed isolatedly

The problem of development modeling is too complicated as one has to wait for moment when it would be possible to analyse all the regions and the national level in a joint model. This led to the decision to analyse an isolated regional economy. In this case, however, it is important to discover what kind of outer information is better for regional forecasting to obtain more reliable results. Here one can analyze three groups for the future:

1. Information about the shipment of goods and services in and out of the region.
2. Information about government (outer) capital investment and shipment of raw materials and goods into the region.
3. Information about prices (marginal costs) of products and resources.

The first kind of information is very instable. Without the analysis of the situation in a country as a whole and in other regions it is impossible to obtain this data for a long-term forecasting period. Usuall, interregional, intersectoral models are used for such kinds of calculation. Naturally, to elaborate this model as an auxiliary to the regional one is none-sense: auxiliary work requires much more time and effort than the main work. An attempt to use econometric models, as was mentioned earlier, does not work for long-term predicting.

The same may be said about the second approach. To calculate the flows of raw materials, goods and capital investment, from other regions into the region under investigation, one requires this kind of information for all the regions of the country. Only now with this data and inner possibilities of the region can one forecast its future economic development (and for this process, the method of estimation of results of the regional economic activities is required).

The third approach is based on the assumption that to predict the system of prices of goods is easier than to predict an interregional flow of goods, (without a special model).
At the same time it seems that the ratio between the future and present prices of goods will be more or less stable due to the following: in the case when these prices change (for example as a result of the fuel prices growth) it would be possible to use the system of marginal costs for fuels for the future, which is presently elaborated at the International Institute for Applied Systems Analysis, in Laxenburg, Austria.
Applied Systems Analysis, in Laxenburg, Austria.

Knowing the percent of expenditure for fuel, energy, labor and so on, and the cost of particular goods, it is possible to bear the corrections which are necessary. The approach to the regional model which is based on this assumption is shown in Figure 4.

In this system of models it is conditionally ear-marked to four stages of analysis:

a) regional specialization problems;
b) location of different sectors of the economy;
c) problems of labour, capital and finance; and
d) problems of human settlements and pollution.

The region specialization is considered here as a starting point for analysis. Using ifnormation about marginal costs (prices) each sector of regional economy builds its own "reaction function", e.g., using a sectoral optimization model, construct an "effect / number of used labour" function. Labour is chosen as a "general" resource but principally it is possible to use another resource or (as in a common case) use a number of them. Then, solving a task of non-linear programming (Figure 5) one can obtain an allocation of labour between activities, e.g., to obtain a preliminary plan of the regional specialization (if a second iteration is wanted then it will not be enough for this plan to be used as a final one).

As a formal solution one estimates that through "the prism of labour" the final aim of the analysis may be formulated as the following:

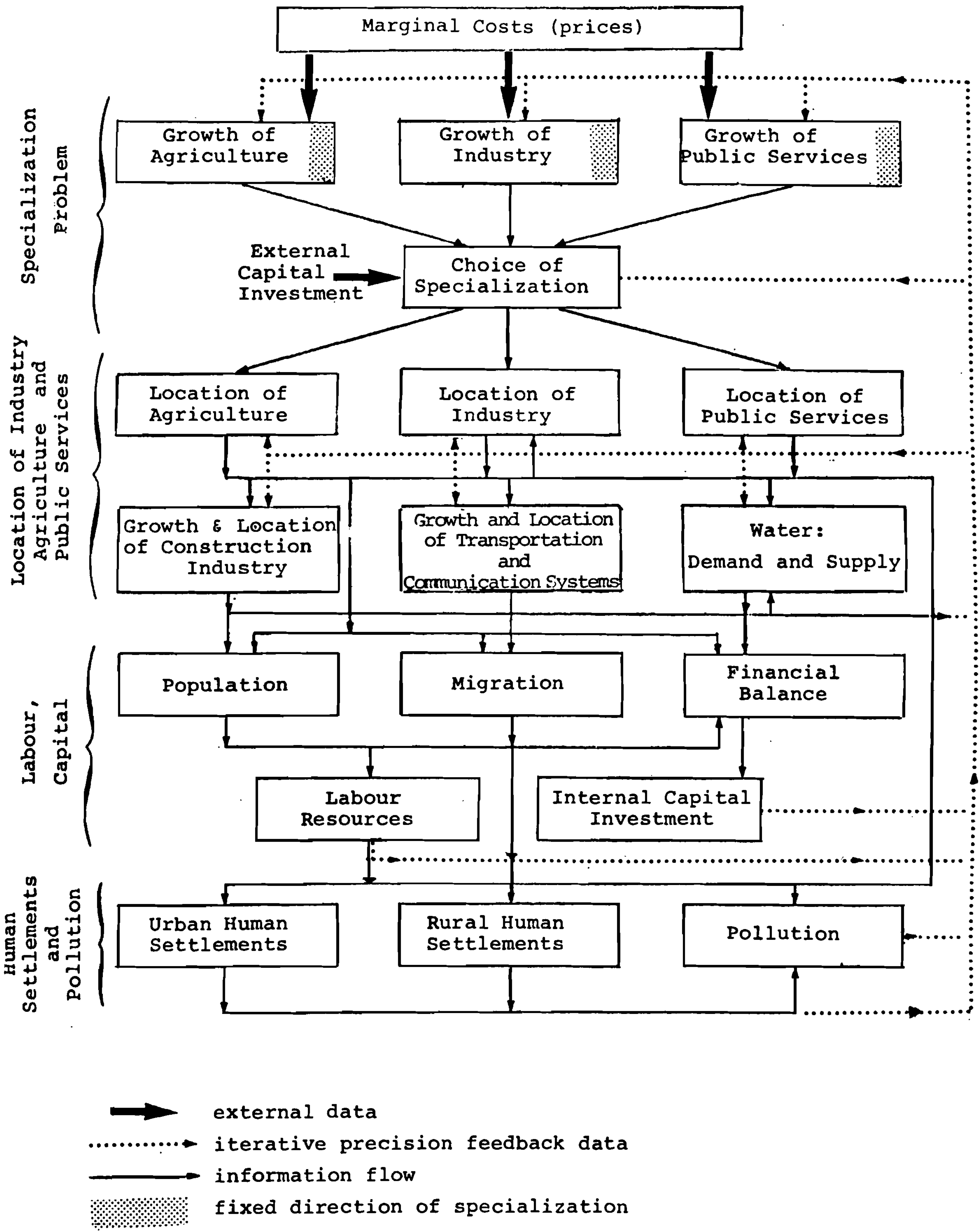
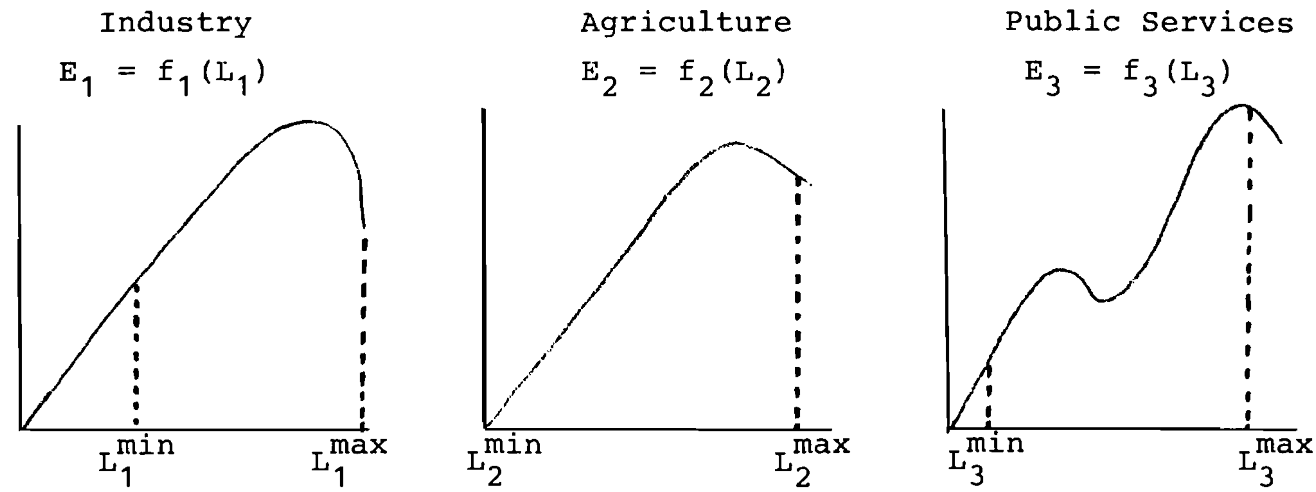


Figure 4. Preliminary Scheme of the IRD Study

1. If one has three "reaction functions":



2. Kinds of labour are substituted* and limited:

$$(L_{max} < L_1^{max} + L_2^{max} + L_3^{max})$$

it is then possible to solve:

$$\sum_i E_i\ (L_i) \longrightarrow \max$$

subject to:

$$\left.\begin{array}{l} L_1 + L_2 + L_3 = L_{max} \\ 0 \leq L_i^{min} \leq L_i \leq L_{max} \end{array}\right\} \quad \text{for all } i$$

Figure 5. Allocation of Limited Labour Potential Between Sectors

*In reality one needs (at worst) to share labour over 3-6 groups.

On a basis of detailed analyses of economic, socio- and political situations in a given region, and taking into account all the main constraints, find out the allocation of regional labour resources (migration included) between the possible direction of their utilization, which will deliver the maximum effect to the whole country.

To know the allocation of regional labour resources one has to define:

a) how much man-power is used in each sector of the regional economy; e.g., to know the rate of growth of each sector of the economy; and

b) how much man-power is used in each sector of industry, agriculture, etc. in each subregion; e.g., to know the intraregional specialization and intraregional location of productive forces.

In order that all data be determined while taking into account all constraints, to know the labour resources allocation is equivalent to the determination of the plan of regional development.

The problems of the location of enterprises in each sector of the regional economy are analyzed on the second level. Here it is very important to chose correctly the sequence of analyses, to simplify the solution and to avoid an additional cycle of calculation. For example, at the stage of the task of the allocation of intraregional agriculture, the preliminary characteristics of the costs of water in each subregion must exist, but their final and more precise definition could be fulfilled only after the optimization of the block "Water demand and supply", for which the first variant of the location of all kinds of activities must be found.

The second important problem here to analyze is the sectors by groups in order to have principal feasibilities to introduce and estimate the effect of joint construction and exploitation of groups of enterprises as part of the complex. Experience shows that it essentially complicates the model and calculation procedure [9].

On the third level of analysis one of the central problems is that of migration which defines the final population and labour resources of the region. It is necessary to say that on this level of analysis the econometric approach seems to be the main tool. The task is to classify all the cases and to elaborate an approach which includes all the main factors which are important when the problem is solved. For example, in the paper by Bertolazi and La Bella the following formula for migration was elaborated on the basis of analysis of the situation in eighteen Italian subregions [10]:

$$M_i(t+1) = a_i M(t) + b_{i1} \frac{\overline{P}(t)}{\overline{R}(t)} R_i(t) + b_{i2} \frac{\overline{P}(t)}{\overline{D}(t)} D_1(t)$$

with $M_i(t) = \sum_{j \neq i} M_{ij}(t)$

where:

i = index of region

t = index of year

a_i, b_{i1}, b_{i2} = coefficients

M_{ij} = net migration from region i to region j

$\overline{P}$ = national population size

P_i = population size in region i

$\overline{R}$ = net national product

R_i = net regional product for region i

$\overline{D}$ = number of unemployed on the national level

D_i = number of unemployed in region i

Figure 6 : Formula of migration in Italy

In this formula the decisive factors are the migration flows of the previous year, the level of productivity in the region and the level of unemployment.

This approach which is a good one for Italy and also maybe for other countries with a market economy does not correspond to the conditions of the planned economy countries where no unemployment exists. At the same time one needs to investigate additionally the influence on the process of living conditions in different parts of the country and the age-structure of the population. The former problem is very important for the Soviet Union with its variety of climatological conditions, the latter problem is now very important for the USA and many other countries, where the old people often migrate from large industrial towns to small but quiet and pleasant ones. Therefore a generalization of the approach to the description of the migration process is required.

The classification of the population is required to describe correctly the constant or temporal impossibilities to substitute labour in different parts of the regional economy activities. The solution of this problem is closely related to the depth and detailedness of the description in the regional model of the process of sectoral activities (number of sectors), education and so forth.

The regional finance flows analysis which is considered on this level will give the possibility to check the balance of income and expenditures and the possibilities of using inner finance resources for further regional growth.

In the final stage it is essential to estimate, generalize and implement the formal methods of forecasting growth (change) of rural and urban human settlement systems. To formulate this task, not from the viewpoint of choice of the optimum decision for one particular city, but to try to obtain an optimum decision for the whole system of regional settlements is a complicated but important task.

The last block is that of pollution. This task is one of the most difficult from the viewpoint of complexity of its generalization. Nevertheless it is imperative to formulate all the requirements of this block with the needed information because these last may have an important significance during the modeling of other blocks of the system. As an example one should mention the classification of pollutants which is very important during the choice of the number of the industrial sectors, analyzed on the first level.

Conclusion

In this paper it is impossible to touch on all the details of a preliminary system of models of the regional economy. It is important to underline here that the system must be able to analyze in detail long-term regional development and that to to do this one must combine the many known tools including optimization, simulation, input-output balance, and an econometric approach.

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