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Regional Systems Analysis: From Theory to Application

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ABSTRACT

Regional policy problems are universal. This means that all countries need good methods for analyzing and solving their regional problems. Models for regional policymaking and planning have also been worked out in scientific institutions. It is obvious that these abstract models are often not specific enough to be used in policymaking but have to be adapted to the institutional, historical and natural conditions of the specific models within a comprehensive system analytical framework. It is one of the ambitions with the approach to regional case studies reported in this paper, to test the possibility of applying regional policy models to the solution of regional development problems and to regional planning issues. This paper describes briefly the work on this topic undertaken by scholars within the Regional Development Task and elsewhere at IIASA.

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REGIONAL SYSTEMS ANALYSIS - FROM THEORY TO APPLICATION

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INTRODUCTION

IIASA is currently engaged in case studies of regional development in agricultural regions of Bulgaria and Poland and metropolitan regions in Sweden and Italy.

The purpose of these studies is the creation and practical use of integrated systems for regional and sectoral development. The basic approach of these studies is to analyze the development problems of the regions in the framework of national and regional policies. The problems analyzed concern investments in sectors of production, use of energy and other primary resources, interregional location, population and transportation policies, planning of new and existing towns and the construction of industrial and agricultural production complexes.

The broad range of these case studies has made it necessary to find some basic principles of regional systems analysis which can cover different political systems as well as regions at completely different levels of agglomeration.

It is evident from our work on regional development at IIASA that the methodology must be developed so that the regional policymaking can get better tools to cope with the essentially dynamic, uncertain, and interdependent factors regulating long-term economic and technological growth and structural change at the regional level. This paper is aimed to outline some of the basic principles of applied regional systems analysis as it has been practiced at IIASA.

APPLIED REGIONAL SYSTEMS ANALYSIS - A Definition

To qualify as applied regional systems analysis a study must have a clear policy orientation. This has at IIASA implied a focus on case studies of actual regions with a proper cooperation with policymakers and planners of the region and the country of the case study.

Regional systems analysis is also oriented to long-term problems of policymaking; this means a view to strategic rather than tactical and operational policy issues. In the economic analysis which is at the core of these case studies it has further meant an orientation to an analysis of economic development in long-term perspectives. At the regional level one is then forced to study not only growth problems which are theoretically well understood, but also problems of secular decline--a rare phenomenon in national economies but not uncommon at disaggregate levels. It is also obvious that one must study structural change in regional long-term case studies. The problem definition is very often in terms of generating policies for change of the structure of production, real capital and the labor force.

Long-term policy analysis implies by necessity that there are some well-behaved as well as ill-structured uncertainties involved in the problem. It is for instance rather hard to predict a population, its propensity to work, the availability of local resources and other basic variables. It is even harder to generate good predictions for future demand structures in the region and its surrounding world. To make reasonable quantitative predictions about the technology and the political valuations ruling two or three decades ahead is close to impossible. For this reason we have drawn the conclusion that scenarios, structural sensitivity analysis and similar approaches must be used extensively to provide some insights into the consequences of the fundamental uncertainties of long-term regional policymaking.

Applied regional systems analysis means that economic, ecological, technological and demographic systems must be related to each other in an essentially dynamic and spatial systems analysis. This implies that a large number of variables have to be interconnected with each other. This means model building that requires a very sensitive trade-off between realism, simplicity and possibility of estimation.

PURPOSES OF MODELING

In operations research and in other tactical business analysis with quantitative models the aim is often to generate some quantitative policy recommendations. This is also one of the ideas behind macroeconomic modeling for fiscal policy purposes as outlined by Tinbergen and other econometric policy model builders.

Applied regional systems analysis cannot have this kind of aspiration. The orientation to long-term policy problems makes it impossible to give any policy recommendations which are certain enough to warrant very exact conclusions. A moderate goal with some realism would rather be to use the models in such a way that some qualitative policy recommendations in the form of "rules of thumb" can be generated. With this, I mean some directional information on policy instruments in cases of substantial changes in the environment of decisionmaking.

But even this level of ambition is in some cases too high. In such cases applied regional systems analysis can at least be used so as to create a better understanding of the long-term regional policy problems and their interactions. To use models for this purpose, it is very often needed to generate a large number of projections which can trace out the consequences of different assumptions concerning parameters and functional forms. Such projections are often called scenarios and are thus an essential aspect of applied regional systems analysis as I have come to understand it.

OPTIMALITY AND THE GENERATION OF SCENARIOS IN REGIONAL PLANNING

It is argued in this paper that the creation of different scenarios is a necessary feature of the planning process. Such planning scenarios can be developed through a purely verbal process, but this verbal process can also be aided by sketching as is often done in physical planning. However, experience shows that such a procedure is only viable, if the number of planning variables is extremely small. This implies that computer-assisted planning procedures grow more useful and necessary when the number of fundamental dimensions and their degree of disaggregation increases.

Economic structure can be seen as one dimension of the planning process, the regional structure can be viewed as a second dimension, and the temporal structure of activities form a third dimension. If we were to assume that the economic structure could be represented by 30 production sectors, the regional structure by 10 regions, and the temporal structure by only three time periods, the minimum total size of a model featuring all interdependencies would be 900 variables. Thus, it would be very difficult to construct a plan for such a system without the aid of a formal computer model.

In the early theory of planning, it was often assumed that such a large system must, by necessity, have one and only one global goal function, which should then be maximized, subject to certain technological constraints. Adopting the same planning paradigm, one should then construct one giant model for the the whole system, and maximize the global goal function subject to the possible variations in the variables, which could be viewed as the instruments of planning.

This approach can be criticized for at least three different reasons:

(a) It is not yet certain that it is possible to construct an empirically reasonable, yet numerically computable economy-wide optimization model containing spatial, sectoral, and dynamic subdivisions.

(b) It is doubtful whether policy makers are willing or able to state their valuations in a form suitable for programming purposes before they have discovered some means of identifying the consequences of their valuations. It is thus disputable if any single goal function can be determined before the start of the planning process. The most appropriate valuation might have to be determined within the planning process, implying that policymakers should really be involved throughout the modeling procedure.

(c) Having introduced a spatial subdivision, it is very likely that the preferable goal functions for each region will not correspond to any single global function for the whole system.

Clearly, the a priori selection of a single global goal function for the planning process is a difficult and dangerous task. A more meaningful approach might be to suggest a number of difficult possible goal functions, and then to study the range of solutions obtained. This could overcome the last two problems [(b) and (c)) mentioned above, but it would still suffer from the first uncertainty. In summary, it is felt that the numerical capacity of any optimization model which contains spatial, sectoral, and temporal dimensions presently remains very limited in the emprical sense.

But a further difficulty is evident. Most planning models can be given quite a concrete and statistically reasonable specification when it comes to those constraints which have a clearly technological background. This is certainly the case with resource use constraints. Most planning models for an economy contain reasonably accurate constraints on the use of primary resources, labor, and other factors of production.
The interdependencies between the sectors can also be specified with some degree of precision. It is, however, far more difficult to specify the behavioral constraints which regulate the activities of the households (consumers) and other decision-makers in the economic system. It is thus probable that any optimization model for the planning of an economy will be underdeveloped with respect to the specification of behavioral relationships.

THE CHOICE OF SYSTEMS ANALYSIS APPROACH

Regional systems analysis is an application of systems analysis to policymaking in a dynamic and spatial perspective. Space can be handled in essentially two ways. We can either analyze the problem in continous space as proposed by Martin Beckmann, Tonu Puu, Walter Isard and Edwin Mills, inter alia. The other principle is to subdivide the total space (for instance the nation) into a discrete set of regions. We have in our development of a systems analysis approach to regional development generally chosen the discrete, regional approach to spatial analysis. In most cases, we have also chosen to handle time as a discrete set of time periods.

Principles of Regional Decomposition

In a purely theoretical general equilibrium analysis of the kind proposed by Debreu (1959)[1], each decision variable, for instance the quantity to be produced, is indicated by time, decision maker, type of commodity and region. To prove the existence of a solution to such an interregional equilibrium problem, even with an infinitely large number of consumers and producers, is not impossible in a static situation. However, this approach requires a large number of simplifying and not very realistic assumptions about convexity of preference and production sets. Such assumptions are normally not valid in the real world.

The extension of this approach to realistic transportation-communication technologies and situations of growth and development has never been possible as an extension of the basic static theory. To cope with policymaking problems in such a dynamic, interdependent regional production and consumption system, decomposition and simplification is necessary. Simplification through decomposition and structuring of the regional development problems

[1]Debreu, G. Theory of Value. Cowles Foundation Monograph, 17. New York: John Wiley and Sons Inc., 1959.

has been proposed by many analysts in the market-and plan-oriented economies. Some prominent names in this field are Walter Isard, Vasilii Leontief, Abel Aganbegyan and Alexander Granberg. Common to the approaches of these scientists is simplification through linearization of technologies for production, transportation and consumption of commodities. With linearization, it is mostly possible to solve problems with hundreds of regions and a rather large number of production sectors and different categories of households.

Two types of criticisms can be raised against the linearized approach proposed by Leontief and others. The first criticism concerns economies of scale in production and transportation of commodities. Economies of scale in production leads to non-linearities, which however, for sufficiently large regions are of limited importance. Leontief and similar world regional modelers can thus claim that linearization is of no real importance for their regional policy problems. In a national regional problem fomulation, one must however take this criticism seriously. The regions which form a part of a nation are normally rather small and economies of scale cannot be disregarded in the model formulation.

Furthermore, transportation and communication are phenomena which cannot, according to modern transportation-communication theory, be linearized but are non-linear on any scale of aggregation. It can, in fact, be argued that the higher the level of aggregation, the more non-linear it becomes.

From this point of view our approach to regional systems analysis has not been limited to simplification by linearization but in the cases where the linearization was justified, it was widely used.

We have rather chosen to simplify the long-term regional policymaking problems through decomposition of the total problems into a set of interlinked models. These submodels are linear, non-linear, integer or real-valued in accordance with the best formulation of the problem and the technologies and behaviors reflected by the models.

Decomposition and Structuring of the Regional Policy System

In decomposing a regional policy problem, there are basically three principles.

A. A procedure based on successively constraining policy actions from an international through a national, down to the regional level (Top-down approach).

B. Another approach is to start with the planning of the individual region, aggregating those plans up to a national level, and then confronting the regional and national aggregates with the world markets. (Bottom-up approach).

C. A third approach is to analyze interactions on an aggregated sectoral level with explicit mutual regional interdependencies.

It has often been assumed that these approaches are related to different institutional frameworks. This is only partially true. It is true that international organizations tend to prefer the interdependency approach. It is also true that planning in some fairly decentralized countries like the Scandinavian, has been more oriented to the "bottom-up" approach. In reality, the scale of the region is more important for the choice of approach. A relatively large region cannot disregard the impact of its policies on other regions and even on the nation as a whole. In such a case, it is fairly natural to use the interdependency approach in which the policies of the large regions are considered simultaneously in its national context. In the case of small regions, one can safely disregard the effect of each one of the small regions on other, larger regions and the nation as a whole. In these cases causality tends to go in a one-way direction. International and national technological and market development determine the action possibilities for the regions, while it can be safely assumed that the actions taken in any single region will not influence national and international development to any significant degree.

THE HIERARCHICAL APPROACH TO REGIONAL SYSTEMS ANALYSIS

Most individual regions are, in comparison with the country as a whole, small in terms of employment, capital, land use, and production. This means that decisions taken at an international or national level on the development of technology trade patterns and specialization of production will be important constraints for the decision maker at the local level. This implies that it becomes extremely important to predict economic development at a national level and its regional consequences in order to use these development scenarios as constraints external to the planning of the individual region.

It must be stressed that the construction of such national and international scenarios do not necessarily have to be developed by central research and policymaking institutions. In theory, and very often in practice, such scenarios can be developed within a small region.

The hierarchical approach to regional systems analysis means that the research starts at the international level to generate some constraints on national development. The national development is then analyzed with some emphasis on sectors of production of especially large importance for the region under analysis. The national scenarios should be oriented to possible development of prices, commodity production and investments in machinery and construction capital. These national scenarios should reflect consequences of different situations of energy supply, public sector and private consumption, expansion alternatives.

A national scenario provides the *interregional location analysis* with its most important development constraints. Another type of development constraint for the region comes from the population and labor forecasting activity. A third type of constraints comes from the development of local resources like water, land, mineral resources, etc. At the interregional stage of analysis, the locational possibilities for the region as a whole is determined by a consistent procedure for calculating sectoral development in all the regions. The results of this analysis can then be used for the really policy-oriented analysis for a region--the problem of allocation of land use to industrial, agricultural, service and housing activities. The outline of this hierarchical planning method is given in Figure 1.

1. Technological Development *

Reasonable economic development forecasts must be built on some ideas of develoment of technology. In a country like Sweden with a fairly small total research and development sector, most of the technological advances are imported from other countries. This means that the technological analysis must be focused on diffusion of technology and its innovation in industry. A model for analysis of these problems has been developed in 1979 and is presented in the Working Paper of the International Institute for Applied Systems Analysis, WP-79-12.

2 and 5. International Location and Trade

A fairly extensive work on an international trade model has been developed in cooperation between the Systems and Decision Sciences Area of IIASA and the University of Maryland. This model is built on an assumption of slowly changing trade shares which are moderated by the development of prices of traded commodities in countries of production and on the world market. The development of production potentials and prices in the countries analyzed in the trade model is given by dynamic input-output models of the type constructed by Clopper Almon and Douglas Nyhus. These models are based on dynamic input-output theory. *(5)*.

3. Prices and Factor Rents

It is important to generate the scenarios for the development of relative prices of different industrial inputs and outputs and of factors of production like energy, capital, and labor. For price scenarios, a model has been developed in the Systems and Decision Sciences Area by Lars Bergman and Andras Por. This model which must be fed by external assumptions about the availability of capital and labor, equilibrium prices for future years

*The numbering refers to the models as indicated in Figure 1.

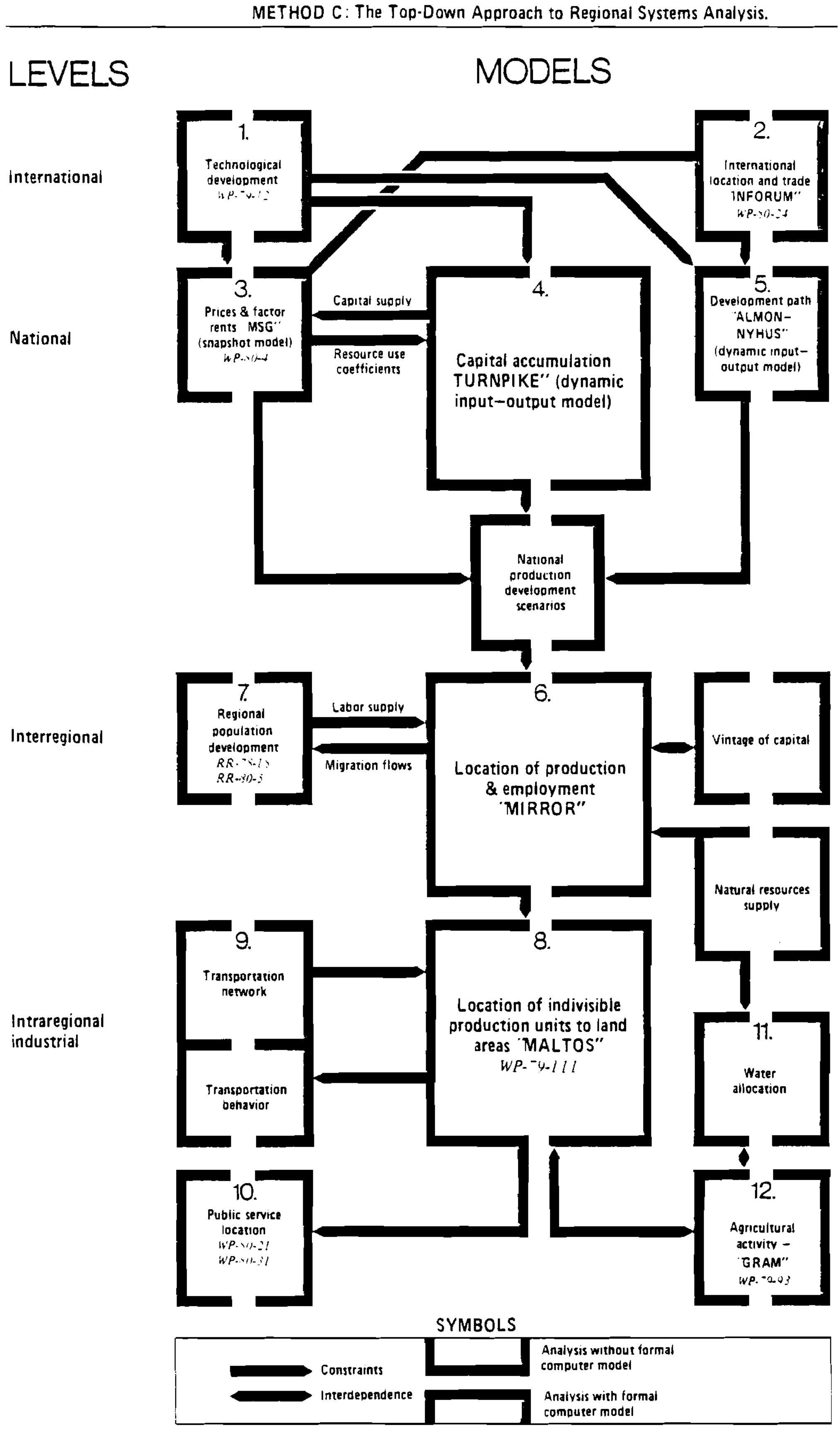

Figure 1. Method A. The Top-Down approach to regional systems analysis.

can be calculated. This model has been used for generation of scenarios for the Swedish nuclear moratorium consequence investigation. As an example of its use, one can cite the result from the imbalance study with the models for the 1970s. In order to establish an equilibrium of the Swedish economy, the model's results indicated that energy use should be contracted with approximately 10% with an increase in the price with approximately 20%. According to the calculations, employment should be reduced in shipyards to 2/3 of its 1975 values. The calculations also showed that housing services should be contracted with 10% of its 1975 volume. To achieve this, an increase of the real price of housing with 15% was warranted.

This model can, for instance, be run for different possible economic situations in 1990 and 2000.

The main drawback of this model is its need for externally calculated capital and labor supply.

4. Capital Accumulation

To get capital accumulation scenarios a dynamic input-output model has been constructed which includes endogenous generation of capital stocks and thus also investments in all the sectors of the economy. This dynamic input-output model also generates growth of production scenarios, which can be compared with the production scenarios implied in the Bergman-Por SNAPSHOT model. Production scenarios are also generated in the "ALMON-NYHUS" model mentioned in Section *2*.

The result of the models *3*., *4*. and *5*. must be summarized in national production develoment scenarios.

6. Location of Production and Employment - the MIRROR Model

At the next stage of analysis the interregional location of employment, investments and production for which a model called MIRROR is used. This model uses as initial information the national sectoral scenarios as well as regional information about population growth and regional employment policies. Availability of natural resources in the region are also used. The fact that all changes in location patterns must be slow because of the already invested material and human capital is reflected in the goal function which minimizes the restructuring or spatial reorganization of production or employment.

The accepted growth scenarios in terms of sectoral production and investments can be used as constraints on the aggregated regional development in macro regions. The population development as projected by the HSS model which has recently been adapted to a large number of regions can give labor supply scenarios for up to 26 regions. Sectoral production for the nation as a whole and employment scenarios for the region are then used as constraints on the interregional location models, MIRROR. The natural inertia to relocation of production is built into the goal function of the model. The essential idea is to search for a location of production that can fulfill the sectoral production scenarios and the regional employment goals together with sectoral and regional resource constraints, while at the same time, it minimizes the restructuring of employment.

8., 9., 10., 11,. 12. Intraregional Analysis

The allocation of activities with the help of the MIRROR model creates the basis for the next step - the analysis of intraregional problems. For this purpose a model for intraregional dynamic location of indivisible units of production has been developed in cooperation with the Systems and Decision Sciences Area. This model, MALTOS, allocates indivisible areas of land to the different production sectors over a discrete set of time periods.

This model is a multi-objective quadratic integer programming model with a set of different evaluation criteria:

- o investment, demolition and operating costs (linear);
- o accessibility of sectors of production and consumption to other activities and prelocated resources (quadratic);
- o node congestion costs (quadratic); and
- o environmental synergism costs (quadratic).

In this model which can also be classified as a combinatorial design model, patterns of land use can be generated.

Because of the non-convexity of this problem, the need for a large number of scenarios must be stressed more than in connection with any other model of this package. As a rule, we can expect to have many local optima, where each one of the local optima can have fairly similar values of the goal function.

The results of MALTOS can be used to generate constraints for land use in the more detailed analysis of service location, detailed industry location, transportation behavior, etc.

SOME PROBLEMS FOR THE FUTURE OF REGIONAL DEVELOPMENT ANALYSIS

In this paper a procedure for regional systems analysis has been proposed. This procedure is based on a case study orientation of regional systems analysis. This means that the problems that are solved are generated by policymakers as they exist in a region with their historical biases and institutional constraints. Much of the "free" research does not accept this link between actual policy makers and analysis. They argue that problem formulation should be policy oriented but not necessarily defined by current decision makers. It is not possible to give any strong arguments against this point of view. It might be necessary for systems analysts at institutes like IIASA to try out a free problem formulation to supplement the results of case studies with their link to policy makers' definitions of policy problems.

The methods advanced in this paper are also biased in the sense that they all rely on fairly hard mathematical methods. Some problems are however, inherently hard to formulate in mathematical terms, and yet of importance for decisionmaking. In this category we have to count both human relation problems at the micro level as well as the political macro level. This means that systems analytic approaches employing mathematical models must necessarily be complemented by more soft approaches related to the problems defined by the humanistic and some social and behavioral sciences.

I have argued in this paper that there are fundamental uncertainties associated with applied regional systems analysis. Sensitivity analysis with the programming models and even formal stochastic programming can be of some help in handling these uncertainties. In the very long run it is, however, necessary to use methods of structural stability analysis to realize the possible changes in the fundamental structure of regions. But the fundamental uncertainties should not only be handled in the modeling of regional development. The actual design of regions which is one of the core problems of regional systems analysis can also take the fundamental uncertainties into account. This means that the development scenarios should not only be judged in terms of their benefits, costs, accessibilities, environmental impacts and similar easily quantifiable consequences. The different plans should also be judged with respect to their inherent adaptivity, flexibility and resilience with respect to unforeseen changes of behavior and technology.