AN INTERDEPENDENT FRAMEWORK FOR INTEGRATED SECTORAL AND REGIONAL DEVELOPMENT

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PREFACE

The work on regional development at IIASA is oriented to problems of long term growth and decline of regions and systems of regions. The understanding of long term regional development problems is closely related to an understanding of the interdependency of factors determining economic growth.

This paper is devoted to modeling of economic growth and the possibilities of creating numerical models of national, regional and interregional computable growth models. The basis of the models presented in this paper is the dynamic input-output theory. It is shown to be possible to implement such a model even if data on marginal capital-output coefficients are not available. It is furthermore shown that regionalization of the dynamic input-output model is possible if an information theoretic approach to estimation is used. The program for estimation of regional input-output and capital-output coefficients has recently been implemented on computers in Bulgaria and is intended to be used also in the Swedish case study. This program is developed and implemented by A. Por.

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Abstract. In most countries there is a need for a technique to develop consistent sectoral and regional scenarios for long-term planning or forecasting purposes.

This paper presents a set of models designed to satisfy this requirement. The models are based on dynamic input-output theory, without the linearity constraint.

The focus of these models is on long-term problems and we have therefore concentrated the analysis on scenarios of the general equilibrium type. The models have been constructed so at to be applicable also in situations of limited statistical information in terms of capital trade flow measurements. The method has been applied to market and planned economies. Numerical problems are discussed in the paper.

Keywords. Economics; eigenvalue; hierarchical systems; linear differential equations; matrix algebra; models; nonlinear systems; numerical methods; parameter estimation; transportation.

INTRODUCTION

Any region is extremely open (or trade-oriented) in comparison with the nation of which it is a part. Consequently, effective regional planning must take proper account of various development patterns occurring outside the region itself. To do this in a comprehensive fashion, each region needs to recognize its interdependency on all other regions which contribute to its economic and political environment.

To achieve a consistent network of regional planning, interfaces can be merged at the national level in the form of national economic development scenarios. For the generation of such national scenarios, a number of different modelling approaches are possible. A primary general requirement is that the models be dynamic in the sense that investments are endogenously determined. There are then two broad classes of models available for dynamic economic forecasting and planning: the neoclassical or the interindustry type. Within each of these classes, both equilibrium and optimization formulations are possible. Furthermore, either open or closed versions on each model may be studied.

We have chosen to concentrate on interindustry models with elaborated trade analysis and of the equilibrium type.

THE NATIONAL GROWTH PROJECTION PROBLEM WITH INCOMPLETE DATA

The problem of projecting the equilibrium growth solution for an economy can be formulated in the following way. Let us assume that total production in each sector of the economy can be used either for current purposes or for investment in a stock to be used in the future. For each sector we thus have the requirement that:

production $\geq$ current use + investment use

The current use of a certain input in a sector can be assumed to be proportional to the level of output of that sector. We thus have the simple relation:

$$x_{ij} = a_{ij}\, x_j, \text{ where } \begin{Bmatrix} i=1,\ldots,n \\ j=1,\ldots,n \end{Bmatrix}; \quad (1)$$

x_{ij} = input of commodity i in sector j for current use;

x_j = output in sector j;

a_{ij} = input-output coefficient.

The input-output coefficient can be assumed to be a constant for a given structure of prices. This substitution problem is discussed below.

Investment use of a commodity is related to the growth of production in the different sectors:

$$\frac{dx_{ij}}{dt} = b_{ij} \frac{dx_j}{dt}, \quad \begin{Bmatrix} i = 1,\ldots,n \\ j=1,\ldots,n \end{Bmatrix} \quad (2)$$

where

b_{ij} = marginal capital-output coefficient.

A solution to the growth problem must therefore be such that

$$x \geq Ax + B\frac{dx}{dt}; \quad (3)$$

where $x = \{x_i\}$; $A = \{a_{ij}\}$; $B = \{b_{ij}\}$

$$\frac{dx}{dt} = \left\{\frac{dx_i}{dt}\right\}.$$

Short-term, Temporary Equilibrium

A short-term temporary equilibrium in this model can now be defined to be such a state that each sector i has the same intensity of resource use γ and their own rate of growth λ_i, predetermined in their planning process. We thus have the following reformulation of our simple growth model:

$$\gamma x = Ax + B\Lambda x, \text{ where} \quad (4)$$

$$\Lambda = \{\lambda_i\}$$

$A + B\Lambda \equiv Q$ and thus $\gamma x = Qx$, where γ is an eigenvalue to be determined jointly with x. Feasibility requires $x \geq 0$ and $\gamma > 0$. Applying Perron-Frobenius theorem we know that the maximal $\gamma = \gamma(Q)$ is the only eigenvalue that has an associated semi-positive x-vector. We further know from the same theorem that any increase in an element Q leads to an increase in $\gamma(Q)$. We consequently know that any increase in the growth plans of a sector will lead to an increase in the intensity of resource use.

Medium-term, Temporary Equilibrium

A medium-term, temporary equilibrium in this model can now be defined to be such a state that each sector i has the same intensity of resource use and that this intensity is equal to 1 under no constraint on the relation between the growth rates.

This situation can be viable for some time, but not indefinitely. Sooner or later bottlenecks will emerge for some slow growth commodities, which will eventually influence the possibilities to grow in the high growth sectors.

Long-term, General Equilibrium

In the long-term, general equilibrium, with a given pair of A- and B-matrices, requires all sectoral growth rates to be the same with the rate of capacity utilization at the same time being equal to 1 in all sectors. This corresponds to the well-known Turnpike solution on which all sectors have a proportional rate of growth, which is furthermore the maximal one for an indefinitely long time perspective. On this path, no bottlenecks or excess supplies will ever occur.

Estimation of the Interindustry Growth Model

The application of this model for the short-, medium-and long-term projection problem requires estimation of the A- and B-matrices. Estimation of the A-matrix is regularly done in most countries, while a complete B-matrix is almost never available. It is, however, possible to generate a B-matrix and some normally accessible information about the growth of the sectors of the economy.

Let us assume with the same arguments used by Lange (1957) and Hawkins (1948) that each capital-output coefficient b_{ij} is equal to a product of the current input-output coefficient a_{ij} and a turnover time t_{ij}. We can further assume as in Brody (1970) that turnover times for a given commodity are the same, irrespective of destination of the commodity. We can then determine

$$b_{ij} = t_i\, a_{ij}. \quad (5)$$

Let us select one reference sector k. We can then express relative capital-output ratios as

$$b_{ij}/b_{ik} = t_i\, a_{ij}/t_i\, a_{ik} \quad (6)$$

$$= a_{ij}/a_{ik}; \quad (i,k = 1,\ldots,n)$$

This procedure thus generates n(n-1) independent equations. We thus need n independent equations to determine the n^2 b_{ij} coefficients to be treated as unknowns.

For this period of observation the growth path of the sectors can be observed, i.e. $\bar{\lambda}_i$, $\bar{x}_i$ and a_{ij} are known for all sectors. We can thus express b_{ij} as variables of

$$\sum_{j=1}^{n} b_{ij} z_j = y_i ; (i = 1,\dots,n); \qquad (7)$$

where $z_j = \bar{\lambda}_j \bar{x}_j$ and

$$y_i = \bar{x}_i - \sum_{j=1}^{n} a_{ij} \bar{x}_j .$$

(6) and (7) together, generate a linear system of equations to determine B.

This procedure to determine the B-matrix has been applied to the American, Swedish and Bulgarian economies. (Batten 1979).

THE REGIONAL PROJECTION PROBLEM

The projection of regional growth of production is an intricate problem even in input-output theory. In a non-spatial input-output model a firm basis for determination of the input-output and capital-output coefficients can be given by the theory of production. According to this theory the determination of each column of the A- and B-matrices (where a_{ij} denotes the requirement of commodity i per produced unit of commodity j and b_{ij} the corresponding ratio) can be seen as a decentralized search for a profit maximizing combination of inputs to produce one unit of output. Through such decentralized search, each sector would end up with one combination of inputs to produce a unit of its' commodity. It is then possible to formulate the standard input-output growth model as a linear system of differential equations.

At the regional level, the relation to the theory of production is much less straightforward. Purchases of commodities must then be looked at in their proper spatial dimensions with a set of reasonable assumptions about how sellers and buyers can establish contacts at a distance. It would, of course, be a simple matter to extend the non-spatial production theory approaches to the regional context. We could then think of the same commodity as disaggregated into different commodities depending on the location of the producer. Each column of the extended <u>interregional</u> input-output and marginal capital-output coefficients can then be determined in a similar profit maximization procedure in which the prices of commodities <u>including transportation costs</u> determine the profit maximizing input to produce one unit of output in a given region. The trade flows are thus to be decided on simultaneously with the levels of production in all regions.

Deterministic profit maximization might be a reasonable approximation in the world of theoretical nonspatial economics. In the world of applied economics in which all actors are separated from each other by physical and social distances, such an assumption is grossly at variance with empirical observations of decisions on trade flows. It is far more reasonable to assume that the decision makers stochastically determine a trade pattern that is consistent with some constraining levels of profits, total input requirements, total output capacities and similar constraints letting traditions, established trade relations etc.

We have chosen to follow the latter, non-optimization and stochastic approach. Such an approach generally generates better empirical estimates of trade flows than what is possible with the deterministic optimality principle. The deterministic optimality principle - if it were true - could only be accurate at the extremely disaggregate level at which no computer-oriented models can be designed and where no data basis exist.

<u>Trade Between Regions</u>

It is possible to avoid some difficulties in working with causal relations between location and trade on the micro-level by using a statistical or information theory approach. The problem can typically be posed in the following way. Certain flow conditions are given exogenously by economic theory, for example, by supply and demand constraints for different regions. Sometimes empirical observations of interregional flows are also at hand. The problem becomes one of estimating the complete trade pattern and of predicting this pattern in future situations. The tools are provided by information theory. A standard example of this approach is the derivation of gravity models. As shown by Snickars and Weibull (1977), it is possible to define the microstates of the statistical distribution in such a way that a priori information about existing flows can be incorporated. This so-called <u>minimum information principle</u> has been shown by Hobson (1971) to provide a generalization of the Shannon-Weaver entropy measure.

To obtain estimates of transportation flows of goods between regions, a similar statistical approach can be applied. Let a_{ij} denote the usual Leontief input coefficient, that is, to produce an amount x_j of good j an input $a_{ij}x_j$ is needed of goods i. a_{ij} is a technological coefficient that is assumed to be independent of volumes and prices (no scale effect, no substitution) and that remains constant over time. It seems to be a natural step to generalize this input-output notion in a spatial context and to introduce a regional input-output relation a_{ij}^{rs}, where rs denotes deliveries from region r to region s. However, as will be clear from the sequel, it is not possible to express the regional input-output relations as a linear function of production volume x, and hence the definition of a_{ij}^{rs} cannot be made unambiguous.

In the case where spatial separation between regions r and s can be totally ignored, an unbiased assumption of deliveries to production, x_j^s from sector i in region r, would be

$$x_{ij}^{rs} = \frac{x_i^r \, a_{ij} \, x_j^s}{\sum_r x_i^r} \quad , \qquad (8)$$

that is, each unit of production i contributes with the same amount or with the same probability. If the number of delivering regions is r = 1, the expression above is reduced to the usual input-output relations:

$$x_{ij}^{rs} = a_{ij} \, x_j^s \quad , \text{ where } x_j^s \text{ is production of commodity j in region s.} \qquad (9)$$

In other cases the quadratic expression for flows x_{ij}^{rs} can be reduced to linear relationships. There is no reason to assume that the introduction of a profit constraint, a distance factor or other frictions would upset this observation. The flows x_{ij}^{rs} are subject to the following general conditions:

$$\sum_r x_s^r = a_{ij} \, x_j^s \quad , \text{ input constraint i, } (i,j = 1,\dots,n) \; (s = 1,\dots,m); \qquad (10)$$

$$\sum_j \sum_s x_{ij}^{rs} = x_i^r \quad , \text{ output constraint } (i = 1,\dots,n) \; (r = 1,\dots,m). \qquad (11)$$

It is evident that the maximum likelihood estimate of x_{ij}^{rs}, taking the constraints above into account, leads to the formula for unbiased transportation flows given above.

Equation (9) can be generalized to include investment flows. According to the acceleration principle of capital formation, the investment terms can be expressed as a linear function of the change of production Δx_j^s. Thus

$$\sum x_{ij}^{rs} = a_{ij} \, x_j^s + b_{ij} \, \Delta x_j^s \quad . \qquad (12)$$

This formulation corresponds to the dynamic version of Leontief's input-output model.

In its simplest form the costs (c) of transportation of goods x_{ij}^{rs} can be expressed as a linear function of unit costs:

$$c = x_{ij}^{rs} \cdot t^i \cdot d^{rs} \quad , \qquad (13)$$

where t^i denotes the cost per value of goods i per kilometer and d^{rs} denoted the distance in kilometers.

It is fairly obvious that communication networks can be included in the same way to represent the a priori constraints of information capacity of the trading system. The information about transportation costs can be used in various ways to constrain the set of feasible transportation flows and hence to affect the most probable distribution of flows. For example, if the capacity in terms of total transportation between each pair of regions is known, then some capacity constraints are

$$\sum_i \sum_j x_{ij}^{rs} \, t^i \, d^{rs} = c^{rs} \quad . \qquad (14)$$

Together with the two previous constraints (10) and (11) the maximum likelihood solution becomes:

$$x_{ij}^{rs} = A_i^r \, x_i^r \, B_{ij}^s \, (a_{ij} \, x_j^s + b_{ij} \, \Delta x_j^s) \exp(-\gamma_{rs} \, t^i \, d^{rs}) \quad . \qquad (15)$$

A_i^r and B_{ij}^s are balancing factors that are implicitly defined by the first two constraints. They depend on the whole trade pattern.

$$B_{ij}^s = \frac{1}{\sum_r A_i^r \, x_i^r \exp(\gamma_{rs} \, t^i \, d^{rs})} \quad , \qquad (16)$$

$$A_i^r = \frac{1}{\sum_j \sum_s B_{ij}^s \, (a_{ij} \, x_j^s + b_{ij} \, \Delta x_j^s) \exp(-\gamma_{rs} \, t^i \, d^{rd})} \quad . \qquad (17)$$

The cost constraint can be defined in other ways, for example, in terms of total costs or total cost per type of goods. The corresponding changes of parameters in the formula for x_{ij}^{rs} are obvious and will not be developed here.

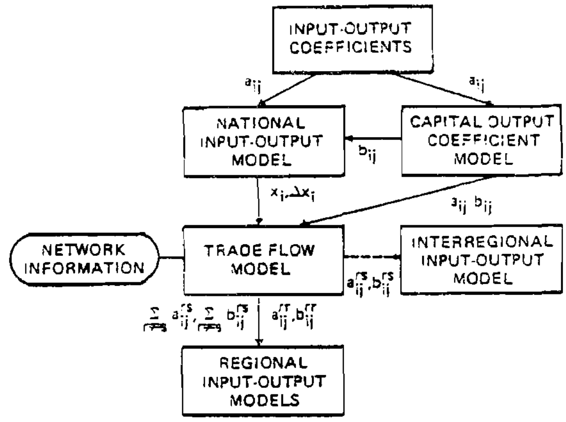
As noted above, there are methods to improve the estimate of the flow matrix (x_{ij}^{rs}) by using a priori information according to the minimum information principle (Snickars and Weibull, 1977). Historical data of flows x_{ij}^{rs} together with actual data (observed or exogenously determined) related to the demand and supply constraints (C) can be used to ensure an "effective" statistical estimate (that is, with the lowest information content).

We have thus generated a set of equations that can be used to determine interregional trade flows resulting from locational choices and different frictions on trade flows. This approach can easily be extended to more general situations. The nature of this theory is that all prior information in the form of theoretical conditions, summation, and other consistency constraints can be easily accommodated and the goal function is only there to give a stochastically determined solution. It is consequently an easy theoretical matter to include constraints on the minimal welfare level of the participants of the trading system, resource constraints, economic block formations constraints, and so on. The consequence of each such constraint is to add prior theoretical determination of the flows and to leave less room for stochastic elements.

CONCLUSION: THE SYSTEM OF MODELS FOR SECTORAL AND REGIONAL GROWTH PROJECTIONS

The models described above can be used to generate national, interregional or regional consistent economic development scenarios. In the interregional modelling, it is necessary to use all the data generated by the trade model as elements of complete interregional and intersectoral input-output- and capital-output-matrices. The procedure for solving short-, medium- and long-term growth equilibrium problems can be used, as outlined in a section above. In the case of a national, single-region growth scenario analysis, only the coefficients relevant to the region of investigation plus aggregated trade information is used.

The interrelation of the models developed is given in the diagram below.



All the models discussed in this paper have been programmed and are available on magnetic tapes from the International Institute for Applied Systems Analysis, Laxenburg, A-2361, Austria.

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