AN OVERVIEW OF REGIONAL AND MULTIREGIONAL MODELLING IN AUSTRALIA

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April 1982
CP-82-18

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PREFACE

The Regional Development Group is engaged in a sequence of comparative studies in regional development modeling. The general purpose of this work is to promote an international exchange of the best experiences and most advanced knowledge in the field.

This paper by D.F. Batten and R. Sharpe was prepared as a contribution to a comparative study of multiregional modelling. It gives a general overview of approaches to regional and multiregional modelling in Australia, describes the main models developed in that country, and gives their characteristics in terms of spatial focus, direction of causal links, and formal types of solution techniques.

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Laxenburg, April 1982

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1. Introduction

The basis for regional modelling - regional theory - is still very primitive. Consequently, the history of regional modelling in general, and multiregional modelling in particular, is relatively short. In recent years, modest progress has been achieved in Australia, mainly by assimilating advanced theoretical techniques developed originally in other countries. The point has now been reached where some Australian modelling exercises have achieved significant international recognition.

In this paper, we present an overview of the regional modelling work in Australia. We begin by developing a general framework to describe the distinguishing characteristics of these models. Important features, such as the model's purpose, structure, spatial focus, and method of solution are considered. Next, a short description of existing Australian models is presented, comprising models designed for a single region or set of regions. We then attempt a simple comparison of these models, followed by a short consideration of trends emerging from similar modelling exercises overseas. The final section offers some thoughts on future directions, by stressing the need for an integrated system of models to generate consistent national and regional development options for the nation as a whole.

2. A General Framework for Model Description

In order to compare the existing suite of Australian models, there is a fundamental need for a general classification system to describe the pertinent characteristics of each model. Very few proposals have been made in this direction (see, for example, Nijkamp and Rietveld 1980). The following set of characteristics are regarded as a fundamental part of any such classification system.

2.1 Spatial Focus

Owing to the generality of the term "regional", we see it regularly used at widely differing levels of scale. For modelling purposes, the word needs further qualification to ensure a precise specification of each model's spatial focus. The following distinctions will therefore be adopted:

REGIONAL - a general term referring to the behaviour of a single region, with no detailed distinctions between the internal and external interactions.

INTRAREGIONAL- a specific term referring to the behaviour inside a single region, with a detailed focus on internal relationships.

MULTIREGIONAL- a general term referring to the behaviour of a group of regions, with no detailed distinctions between the internal and external interactions.

INTERREGIONAL- a specific term referring to the behaviour of a group of regions, with a detailed focus on the relationships between each pair of regions.

2.2 Purpose of the Model

Models can be devised for a multitude of different purposes. Following earlier modelling classifications (see, for example, Lee 1973), at least three basic purposes or perspectives appear relevant:

DESCRIPTIVE/ANALYTICAL models are mainly concerned with describing or analysing the features of an existing or historical regional system. Examples of this type of model include static input-output models, central place theory, and migration models which focus on cross-sectional studies.

PREDICTIVE/FORECASTING models generally attempt to estimate the future state of a regional system by projecting historical trends or extending current patterns. Examples here include econometric models, demographic projections, and various simulation models.

PRESCRIPTIVE/POLICY models attempt to determine the future state of a regional system by prescribing certain instruments ad objectives of various policy units represented in the model. Examples included in this group are linear and nonlinear programming models, balanced growth models, satisficing models, and models using control theory or the theory of games.

Although the above distinctions may appear to be straightforward, many models have been designed to embody elements of each. Consequently, it makes little sense to classify a model for one purpose exclusively (see Sharpe and Karlqvist 1980). The terms predictive and prescriptive may be somewhat unidimensional, since much predictive behaviour often involves optimization by individuals or sub-groups, whereas prescriptive planning and policy-making often strives for predictable goals and objectives. The main advantage of the above distinctions may simply be that they pinpoint the institutional context of the modelling exercise.

2.3 Structural Relationships

Structural Relationships, or linkages between the various spatial units, may exist within each level or between different levels of a modelling hierarchy. These two orthogonal directions allow for

(i) mutual relationships between regions, and
(ii) relationships between region and the nation as a whole.

The first class is subdivided into models which contain interregional linkages, and those which do not. The second class gives rise to four possibilities:.

INDEPENDENT models, in which no relationships are considered between nation and region.
TOP-DOWN models, in which the regions are influenced by national behaviour, but not vice versa. This can be viewed as a process of disaggregation.
BOTTOM-UP models, in which the nation is influenced by the region(s), but not vice versa. In this case, the process is one of aggregation.
MIXED models, in which some of the variables are determined at the national level, while others are defined at the regional level. This approach seems the most acceptable, since it allows for various mutual interrelationships between nation and region.

The distinctions outlined above lead to eight structural classes of regional model (see Table 1). Models of type 1-4 may be called regional, intraregional, or multiregional, depending upon their spatial focus. Models belonging to types 5-8 are all interregional.

Table 1. Structural Classes of Regional Models.

		Links between regions: No	Links between regions: Yes
Links between nation & region	Independent	1	5
	Top-down	2	6
	Bottom-up	3	7
	Mixed	4	8

2.4 Time Perspectives

Here we may choose either DISCRETE time periods, or try to model time as a CONTINUUM, in which variables and parameters change continuously. Furthermore, each model may be organized on the basis of COMPARATIVE STATICS or as a truly DYNAMIC system.

2.5 Classes of Solution

Models are normally developed with a particular solution technique in mind, since the success of a model often hinges on its ease and cost of solution. Existing techniques may be classified as follows:

EQUILIBRIUM solutions, in which a set of equilibrium relationships are solved simultaneously, or progressively. These models are typified by containing as many equations (or relationships) as unknown variables.

ECONOMETRIC solutions, in which statistical (regression) relationships, fitted to historical data, are extrapolated into the future.

OPTIMIZATION solutions, wherein one or more planning objectives are established, and the variables are then determined so as to satisfy the objective(s). Mathematical programming models are a well-known example. Variants of optimization include multi-objective and multi-criteria models, game-theoretical models, and those using control theory.

INFORMATION-THEORETICAL solutions, which may be characterized as the most probable solution in a statistical sense. They attempt to find the least biased estimate of the unknown variables, based on the (partially complete) information available. Examples of this type are entropy-maximizing models, and biproportional models like the RAS and Cross-Fratar techniques.

The last two solution classes are typified by containing fewer equations or relationships than unknown variables.

3. Australian Regional and Multiregional Models

3.1 Intraregional Models

A number of Australian models have been developed specifically for the analysis of a single region. Included amongst these are various land use models developed by the CSIRO and the Hunter Valley Research Foundation, as well as some survey-based regional input-output tables. Foremost among this intraregional work have been two continuing projects in Queensland. One of these is being undertaken by Jensen and his colleagues at the University of Queensland, and deals with the estimation of intraregional input-output tables and their use in regional impact analyses (see Jensen et al. 1979). The other, led by Stark at James Cook University, involves a Forrester-type systems dynamics model to simulate growth in a single region (see Stark et al. 1976). We shall discuss the input-output work first.

3.1.1 Intraregional input-output models

Although Parker (1967) was the first to produce a sub-national table for Australia (a table for Western Australia derived principally from secondary data) the work undertaken at the University of Queensland has subsequently dominated the input-output scene. Over a number of years, Jensen and his colleagues have refined their approach, to produce a technique which applies various adjustments to the national table to allow for prices, international trade, and regional imports. They also advocate the systematic insertion of superior data, whenever reliable flow statistics are available. The resulting system, known as the GRIT technique for generating regional input-output tables, has been applied extensively in a number of Australian studies.

The GRIT technique is predominantly a nonsurvey approach, which attempts to adjust national coefficients for regional purposes. This approach has much in common with earlier attempts to adjust for temporal changes in the national tables, such as the RAS method of biproportional matrix adjustment (see Stone 1962). Some authors have been extremely critical of the manner in which national coefficients have been used for regional purposes (see, for example, Tiebout 1957 and Miernyk 1972, 1976). This is simply because it is most unlikely that a set of adjustments to the national figures are capable of taking all the pertinent regional influences into account.

A number of important structural differences exist between any intra-regional input-output model and its national counterpart. Because inta-regional tables are more open than the national table to which they correspond, exports and imports account for a larger share of total transactions in the region than in the nation. So, the size of the import coefficient in any given column of the intraregional matrix may be quite large, causing local input coefficients in the same column to fall well below those in the national table. For this reason alone, it is easy to understand why the adoption of national coefficients in regional models can sometimes be misleading. Clearly, there are wide variations in export and import patterns from region to region.

Regional interindustry structure appears to be particularly sensitive to short-run disturbances in the region's propensity to import (see Emerson 1976 or Conway 1980), so an accurate picture of the complete trading pattern between regions now appears essential. In other words, a full interregional analysis is required. A survey approach to this problem would be an advantage, but the cost and effort usually precludes this possibility. A nonsurvey approach to the interregional problem is discussed in Section 3.3

3.1.2 Regional systems dynamics

The systems dynamics model developed by Stark and his associates at James Cook University is designed to simulate growth in a single region. The model is actually divided into two parts:

(i) a simulation model of intraregional economic growth, based upon interactions between the region's population and its economic sectors. Activity levels for base industries are provided exogenously.

(ii) a demographic submodel to forecast changes in the population, employment levels, and demand for services, based on the existing population trends and expected migration patterns.

The model is essentially an export-base forecasting model, containing a demographic submodel, which is operated using Forrester's systems dynamics methodology. It therefore involves extensive use of positive and negative feedback loops, which connect the various subsystems.

Systems dynamics models are rather prone to a cumulative build-up of errors, arising from inaccuracies in the parameter estimation of each feedback loop. They often lead to cyclic behaviour, in which the system oscillates between "boom" and "doom" conditions. Since the initial controversy over the world models used in the Club of Rome studies, testing procedures have subsequently been developed to validate the consistency of these models. They can perhaps provide an interesting alternative to those based on more complex sets of equations, but it may still be difficult to interpret results which are submerged in an extensive system of feedback interactions.

3.2 Multiregional Models

Studies involving a group of regions have been dominated by attempts to disaggregate national models into component submodels for each state. The main efforts have come from members of the IMPACT project team. This group was originally established by the Industries Assistance Commission, in collaboration with other government departments and universities. The project continues, somewhat precariously, as a Commonwealth Government inter-agency study, in conjunction with the University of Melbourne. It is a tragedy that such an important Australian project is not receiving the support it deserves.

3.2.1 Regional disaggregation of the ORANI model

The ORANI model is essentially a <u>national</u> model, developed by the IMPACT team to analyse the effects on industries and employment of various economic adjustments. Changes in tariffs, resource exploitation, world commodity prices, the exchange rate, subsidies, real wages, and local pricing policies, are but a few of the many sensitivity studies which the model is designed to perform. ORANI'S basic structure belongs to the Johansen (1960, 1974) class of multisectoral growth models, which linearize the differential relationships between economic variables. Although the number of equations and variables are several millions, the theoretical structure is simple and quite tractable.

The team has subsequently developed a regional disaggregation procedure, which can be run sequentially with the main ORANI program to generate results for each of the six Australian states (see Dixon, Parmenter and Vincent 1978). Their approach is an adaption of the multiregional technique proposed by Leontief, Morgan, Polenske, Simpson and Tower (1965). The principal advantage of the LMPST method is its modest demands for data, created by imposing a simple distinction between regionally-traded (national) and non-traded (local) commodities. It thereby avoids the necessity for detailed data concerning interregional trade flows, by assuming that all demand for local goods is satisfied intraregionally. Each region's share in the total output of each national commodity is treated as exogenously given.

The ORANI disaggregation has been limited to the six states because the necessary data are more readily available at this level, and because there are good geographical reasons (perhaps peculiar to Australia) for expecting the simple LMPST methodology to be successful at the state level. The major weakness of the model is the inherent assumption that each region's input-output structure is adequately described by the national coefficients. This assumption may provide a reasonable first approximation at the state level, but it would certainly be a major source of error at more detailed levels of disaggregation. Factors which cause the regional coefficients to differ significantly include different vintages of capital, materials, and labour (old versus new technologies), different input prices, input substitutions, and wide variations in interregional trading patterns. These differences have stimulated recent research into more accurate means for estimation intraregional input-output tables, as discussed in Sections 3.1.1 and 3.3.3.

If the ORANI-LMPST model was modified to allow for these regional variations, its explanatory power and potential for general application would be greatly enhanced. In the meantime, the existing version offers a convenient first approximation, which may be quite adequate for many state purposes.

3.2.2 Fitzpatrick's model

The model developed by Fitzpatrick (1980) is also based primarily on the ORANI model. Its driving force is a national projection of the future structure of Australian industry, derived from a scenario of developments in international trade, technological change, demographic shifts, and the like. The purpose of the model is to generate a view of the possible structure of regional economies in the long run. The model is not actually dynamic, which has simplified its construction considerably.

As with the LMPST model, a distinction is made between national and local industries. The national sectors are partitioned further into three groups:

(i) those industries whose locations depend on natural resources

(ii) those which are typified by large plants having definite development plans, and

(iii) those which are free to locate anywhere, depending only on production and transportation costs.

The latter (footloose) group of industries turn out to be the most difficult to represent accurately in the model. Their behaviour is set in an optimization framework, in which their locations are determined by minimizing the total costs of production and transportation.

3.2.3 The MRSMAE model

Liew (1977) has developed a regionalized version of Johansen's (1960) general equilibrium model, building upon earlier extensions by Dixon et al. (1977). It is known as the multi-regional, sectoral model of the Australian economy

(MRSMAE). Like ORANI, Liew focusses on the impacts of trade liberalization and other economic policies, but with greater regional emphasis. Unlike the earlier regional versions of ORANI, no distinction is made between national and regional sectors. All commodities are assumed mobile. Labour, capital and land are treated as potential substitutes, with constant elasticities of substitution.

The model is expressed as a set of linear equations, which may be solved to generate an equilibrium solution in terms of regional production, investment, labour, wages, etc. Facility is made for most variables to be specified exogenously or determined endogenously, subject to consistency requirements.

3.3 Interurban and Interregional Models

In recent years, the construction of single-region models, and multiregional models which ignore spatial linkages (e.g. spillovers and feedbacks), have been deemed unsatisfactory for several reasons (see Bolton 1980, Glickman 1980, or Nijkamp and Rietveld 1980). From both the theoretical and the policy-making viewpoint, the need for interregional models is unanimous. Although interregional model-building is a rather recent experience in Australia, it is perhaps in this class of models that Australian work has achieved significant recognition internationally. We shall begin our discussion with an interurban model, and then progress to two interregional modelling exercises.

3.3.1 Interurban hierarchy model

Forster (1979) has modelled the structure of an interurban system, based on the supposition that urban centres are the major operational units in the cooperative system of economic transactions. Such an assumption does not appear unreasonable in an Australian context, since more than three-quarters of the population are concentrated in six or seven major urban centres. Forster's model further postulates that the economic system functions by passing information between different types (levels) of urban centres, and between different types of information processing functions within these centres.

For simplicity, competitive elements within this system (e.g. individuals, firms, industries, towns, etc.) are ignored at each hierarchical level. In so much as the model embodies a theory of cooperating urban centres, it contrasts sharply with central place theory, which postulates a system of competing urban centres. The model concentrates upon the population in each centre. It considers that centres of the same hierarchical rank, but possessing different qualitative links in the hierarchy, may have vastly different populations. This is particularly true for the towns ranked lower in the hierarchy.

Forster's model may be a more realistic representation of the historical development of the Australian interurban hierarchy than that provided by central place theory. In particular, the pattern of retail purchasing can be regarded as governed by the basic structure of the local space economy, rather than the reverse, which has often been assumed in the past.

3.3.2. The DREAM model

A dynamic regional economic allocation model (known as DREAM) was developed at the CSIRO Division of Building Research in 1975 (see Sharpe and Batten 1976, or Karlqvist et al. 1978), principally for use in regional planning studies. This optimization model has an input-output framework, with constraints on the population distribution, migration, employment, production, consumption, investments, imports and exports. The temporal structure is represented by a simple dynamic multiplier principle, which relates capital investment to output in the various sectors (during the same time period) by a set of linear investment coefficients. The net change in capital (gross investment less provisions for depreciation) then serves as a capacity constraint on the level of production in the next time period.

As with the regional versions of ORANI, a distinction is made between products from <u>national</u> sectors, which are transferable between regions (footloose), and <u>regional</u> products which are not transferable. The flow-stock relationships for the regional sectors take a closed form, similar to the usual balanced dynamic Leontief model. A dummy region is used to absorb excess supply or demand within national sectors. A modified gravity model is used to estimate the interregional flows between various national sectors. This gravity model can also be derived using entropy-maximizing methods.

An initial objective of maximizing net surplus (exports less imports less transportation costs) was chosen. More recently, other objectives have been investigated by including production, employment, population distribution, investment, consumption, intermediate demand, import and export terms (all linear), and transportation cost terms (quasi-quadratic), in the objective function. Various combinations have been explored by weighting each term, and discounting between time periods has been used to give greater importance to initial time periods. Thus the objective function, and the choice of constraints, may be manipulated to reflect various community goals.

The mathematical programming formulation can be solved using iterative linear programming techniques or entropy-maximizing methods. The computer program, which is fully operational, has already been implemented in a wide variety of Australian studies (see, for example, Sharpe and Batten 1976, Sharpe et al. 1977, Karlqvist et al. 1978, Sharpe, Ohlsson and Batten 1979, and Sharpe, Batten and Anderson 1981).

Lesse and Sharpe (1981) have recently formulated a control theory version of DREAM, by relaxing the assumption of supply-demand equilibrium. Imbalances between the supply of, and demand for, goods, services, capital and labour (at both the national and regional levels) are assumed to be the main driving force in the economy. These imbalances may be expressed in terms of either quantities or their dual variables, namely prices.

It is further assumed that the economy may be managed by a set of control variables, which direct the trajectory of the economy through space and time along some desired path (e.g. a turnpike growth path where all sectors expand at a balanced growth rate). Control variables may include a subset of prices, wages, output levels, investments and transport costs. The resulting formulation is expressed as a dynamic optimization problem, with an objective which minimizes a discounted weighted sum of cost penalties. These penalties are associated with the supply-demand imbalances, deviations from the desired growth path, and the cost of implementing controls. The formulation also allows for the input of stochastic data, since regional statistics are usually sparse, of variable reliability, and only made available intermittently.

3.3.3 The INTEREG model

To develop an accurate picture of the production structure and trading pattern for any single region, account must be taken of various development patterns occuring <u>outside</u> that particular region, in addition to the supply-demand imbalances within the region. Many of the early attempts to develop intraregional input-output tables failed to acknowledge, or even recognize, the importance of these spatial interdependencies (see, for example, Moore and Petersen 1955, Schaffer and Chu 1969, Morrison and Smith 1974). More recently, the complete interregional problem has been tackled with the aid of information theory (see Batten and Tremelling 1980, and Batten 1981; 1982).

In his INTEREG model, Batten proposes three alternative approaches to the statistic estimation of interregional and intersectoral flows, using a limited database of industrial and multiregional information. In each approach, a distinction is made between flows to intermediate and to final demand. In contrast to earlier methods which have adopted various a priori flow assumptions, he investigates four different cases describing the extent to which information on intraregional demands is available (thereby defining imbalances between intraregional production and consumption levels).

In the first approach, supplies and demands are considered to be pooled on a regional basis. Each case is therefore treated as a form of hypothesis testing, in which the expected frequencies in a four-dimensional contingency table are estimated subject to various sets of marginal constraints. It is possible to solve all four cases using a standard iterative procedure. If a set of nodal (intraregional) capacity constraints are added to the basic set of interregional accounts, an entropy-maximizing (maximum likelihood) approach is necessary. The result is a minimally biased estimate of the interregional flows, which is maximally non-committal with respect to missing information (see Jaynes 1957).

The existence of historical flow information prompts a third approach, namely application of the principle of minimum information gain. Using this technique, an a priori flow distribution is updated to satisfy a known set of interregional constraints. This procedure can be regarded as one of efficient information adding (Snickars 1979).

Batten has also demonstrated the use of information-theoretical techniques using a closed form of Leontief's dynamic model, in which investments designed to expand productive capacity are treated as endogenous flows instead of as part of final demand. Apart from its relevance to the analysis of interregional development patterns, this approach also permits the gross intersectoral flows to be estimated on an interregional basis.

The advantages inherent in Batten's approach relate firstly to the flexibility of the chosen methodology, which caters for a wide variety of pertinent information (expressed in the form of linear equality or inequality constraints), without affecting the solution procedure. This flexibility extends to a mixture of survey and nonsurvey data. Results provide ample evidence of the allowance for cross-hauling, which is also an inherent feature of the methodology. Furthermore, the INTEREG philosophy ensures that the technical requirements of local industries can be distinguished from the interregional trade patterns. This leads to an accurate estimation of intraregional requirements, which are the key to the determination of intraregional input-output coefficients.

Following some initial applications in Australia (see Batten and Tremelling 1980), the INTEREG model has been adopted for a Swedish study of interregional multiplier effects and is currently being tested in Finland by comparative experiments with survey-based tables.

4. A Comparison of Australian Models

Using the descriptive framework developed in Section 2, we can classify and compare the Australian models described above. Table 2 contains this descriptive summary. The following features are evident:

(i) there is a very strong emphasis on economics as the fundamental base;

(ii) a majority of the models have been designed for predictive/forecasting purposes;

(iii) all the multiregional models employ a top-down approach, whereas the interregional models can accomodate a mixed approach;

(iv) there are very few Australian models which are capable of dealing with regional development in the long run; and,

(v) equilibrium solutions have predominated, particularly in multiregional modelling.

Although interregional model-building is still a relatively rare and recent experience in Australia, it is the authors' firm belief that the interregional approach is the most appropriate one in a spatial context. The obvious drawback to the development of detailed interregional models is the considerable cost and effort involved in their empirical implementation. A simple form of interregional model can be derived by considering each region as part of a two-region model (Round 1978): the region itself and the rest of the world. This could lead to substantial improvements in the accuracy of intraregional estimates. While this type of model makes small demands for data, it usually understates the true extent of interregional feedbacks and spillovers. In any genuine interregional system, a basic requirement is that all the relevant regions be treated equivalently and directly, leading normally to the consideration of a large number of regions.

Table 2. Classification of Australian models.

MODEL	SPATIAL FOCUS	PURPOSE	STRUCTURAL	TIME	TYPE OF	SOLUTION TECHNIQUE
GRIT	Intraregional	Descriptive	Top-down	Short to medium term	Information theory	Iterative adjustment
Systems dynamics	Intraregional	Predictive	Bottom-up	Continuous long term	Econometric	Simulation
ORANI-LMPST	Multiregional	Predictive	Top-down	Single period longterm	Equilibrium	Linear equations
ORANI-Fitzpatrick	Multiregional	Predictive-prescriptive	Top-down	Single period long term	Equilibrium	Linear equations & optimization
MSRMAE	Multiregional	Predictive	Top-down	Single period short term	Equilibrium	Linear equations
Interurban hierarchy	Interurban	Predictive	Mixed	Not stated	Equilibrium	Linear equations
DREAM	Interregional	Prescriptive	Top-down or mixed	Multi-period medium term	Optimization	Iterative LP or entropy
INTEREG	Interregional	Descriptive	Mixed	Short to Medium term	Information theory	Entropy maximization

In the following section, we shall take up the question of interregional modelling by broadening our focus to include recent international developments in this area. These contemporary modelling exercises suggest a fruitful framework for the future integration of spatial modelling efforts at a wide range of functional and structural levels. The following discussion is taken from Batten (1981).

5. Future Directions for Australian Modelling

5.1 Theoretical Background

Regional and interregional modelling presently lack firm theoretical foundations. The attempts to generalize neoclassical economic theory, so as to encompass the spatial dimension, have largely failed because of their simplistic approach to the determinants of interregional flows, possibly the most distinctive feature of regional development. Neoclassical economics has neglected spatial factors, such as distance and location, which may be of critical importance in explaining regional growth (Richardson 1973).

Forecast-oriented techniques, such as regional input-output analysis (Richardson 1972) and development planning models (Tinbergen 1967 or Mennes et al. 1969), should not primarily be seen as a contribution to regional growth theory. Their usefulness is related to examining the consequences of specific changes in exogenous factors (via impact analyses or scenario generation), or determining the most likely or most desirable pattern of development, rather than to any improvement in our understanding of the regionalization process itself. It is very much in this latter tradition that the following search for an integrated modelling framework should be viewed.

Although input-output analysis provides an extremely flexible framework for spatial modelling, we have stressed repeatedly that its regional economy is extremely open in comparison with the nation to which it belongs. This has two very important consequences. Firstly, effective regional planning must take into account various development patterns occurring outside the region in question. Thus the model framework should include interregional linkages.

Secondly, regional rates of growth and decline are much more accentuated than on the national level. In any medium to long term forecasting, the repercussions of different growth rates cannot be ignored. Thus the model framework should also be dynamic.

Having established a fundamental need for a dynamic interregional framework of the interindustry type, at least two other important decisions remain. Within the chosen class of models, either optimization or equilibrium solutions are readily available. Furthermore, either open or closed versions of each model may be explored. Our suggestions regarding these properties will be deferred, however, until we have reviewed some existing models which fulfil our basic requirements.

5.2 A Brief Overview of Some Overseas Models

Spatial versions of Leontief's dynamic model were first suggested in theory over twenty years ago (see Moses 1955, 1960). In the lengthy period following this theoretical underpinning, very few models have since become fully operational. Some exceptions are summarized in Table 3. One intraregional model is included in the table, because of its early contribution to the advancement of dynamic modelling. The seven other models are all interregional.

Table 3 is not intended to provide an exhaustive summary, since other models have certainly appeared. The models include therein are simply considered to be representative of the chronological pattern of advancement in this area. A brief discussion of each model follows.

Table 3. Spatial versions of Leontief's dynamic model that have become fully operational.

Model	Author	Year first Published	Model Structure	Objective Function	Method of Solution	National-Regional Linkages	Determination of Trade Flows
West Virginia	Miernyk and others	1970	Open Equilibrium	-----	Dynamic Inverse	Bottom-up	-----
Maryland	Harris	1970	Open Optimization	Minimize trans-port costs	Linear programming	Top-down	Transportation Linear Programming
Indian	Mathur	1972	Open Optimization	Minimize trans-port costs	Linear programming	Top-down	Based on national flow coefficients
Swedish	Andersson	1975	Closed Equilibrium	Balanced growth	Algebraic eigenvalues	Mixed	Maximum Likelihood
TIM	Funck, Rembold and others	1975	Open Equilibrium	Most probable development	Sequential regressions	Mixed	Gravity model
Dutch	Hafkamp and	1978	Closed Optimization	Multiple objectives	Compromise method	Two regions only	Assumed known
MORSE	Lundqvist	1980	Open Equilibrium	Multple objectives	Linear programming	Mixed	Chenery-Moses

5.2.1 The West Virginia model

Miernyk and his associates made the first attempt to implement a dynamic regional input-output model in the late sixties (see Miernyk et al. 1970). The West Virginia model is not an interregional model, but it makes a very useful distinction between replacement and expansion capital. A slightly modified form of the Leontief dynamic inverse is used to project capital requirements.

When tested by Miernyk, the model produced forecasts that were only marginally different from a series of comparative-static forecasts with a relatively simple Leontief-type model. The West Virginian example demonstrates that the analyst must choose carefully between the costs of additional data collection, and and the strategic returns to be gained from a more detailed specification of the relationships between investment and growth.

5.2.2 The Maryland model

At much the same time as Miernyk's work, Harris (1970) attempted to embed Almon's (1966) national model into an interregional framework. His main objective was to forecast industrial activity at the regional level, along with other regional variables including population, income and employment. He used linear programming to solve the transportation problem for shadow prices, rather than to estimate the optimum trade flows. His interest in trade flows was therefore peripheral.

5.2.3 The Indian model

Mathur (1972) implemented a transport-cost-minimising model for optimal regional allocation in India. His open model combines linear programming techniques with dynamic input-output analysis. The Indian economy is divided into 5 regions and 27 sectors, for which three average growth trajectories (zero, 10% and 15%) are examined. Constraints may be imposed on regional trade balances and resource exploitation. Results indicate that the optimum pattern of production is highly sensitive to rates of growth, and to the trade balance constraints (Mathur 1972, p. 220).

5.2.4 The Swedish model

An interregional model which postulates balanced growth in a closed system of regional economies has been proposed by Andersson (1975). The model is of the equilibrium type, and adopts a dynamic interregional growth and allocation model as an organizing mechanism for spatial flows. The allocation of regional production is organized in such a way that demands and supplies are equilibrated at the various nodes in the transportation network. Andersson argues that the transportation system is in equilibrium if it preserves a balanced situation in each of the regionally differentiated commodity markets, and is consistent with goals like full employent and a given level of resource conservation.

5.2.5 The TIM model

Since 1970, six German research groups have been striving towards the completion of a total interregional model (TIM) for the Federal Republic of Germany. An interim report (Funck and Rembold 1975) explains that the model has four components, namely (i) a demand submodel, (ii) an input-output model, (iii) a production submodel, and (iv) a resource submodel. Interregional, sector-specific commodity flows are derived using a modified version of the gravity model. Unfortunately, this research has since been abandoned owing to insurmountable difficulties with data collection.

5.2.6 The Dutch model

Hafkamp and Nijkamp (1978, 1980) have developed an interregional model which links production, investment, employment and pollution on an intersectoral basis. The welfare profile for each region is assumed to contain three elements (production, employment and pollution) which form the basis of a multiobjective decision framework. Solution is by a compromise method, based on a distance metric, which minimizes the discrepancy between the set of efficient solutions and the ideal solution. The notions of satisficing and displaced ideals are therefore implied (see Simon 1957, or van Delft and Nijkamp 1977).

5.2.7 The MORSE model

A recent Swedish model employs a mixed approach to the task of achieving consistency between the national and regional levels. The model (known as MORSE) links the energy sector to the rest of the economy in a multiregional perspective (Lundqvist 1981). MORSE draws on achievements in input-output theory, development modelling, and mathematical programming. Its multi-objective approach combines goals for economic, employment and energy planning into a linear programming framework. The model has many features that are similar to the DREAM model, and is used to analyse the feasibility and consistency of regional developments, with respect to national ambitions in economic and energy policies.

5.2.8 Discussion

What insights can be gleaned from these dynamic interregional modelling exercises? Firstly, there is a definite need for internal consistency between economic behaviour at the national level and aggregate multiregional behaviour. Ths does not imply identical objectives at each level, but simply means that the various parameters must agree with the national totals when summed over all regions. The pioneering interregional models achieved this consistency by employing a top-down approach. Although this disaggregation procedure represents a convenient means of extending national planning systems to the multiregional level, it suffers from a serious inability to quantify the effects on the national economy of changing regional conditions. The ideal interregional model requires a mixed approach, in which some variables are prescribed at the national level while others are determined regionally.

Secondly, traditional optimization models were based on the assumption of independent decision-making units striving for a single objective. In many of the early interregional models, this objective was to minimize transport costs. Fortunately, there is now a growing awareness that planners and policy-makers must really base their decisions on a multiplicity of criteria (e.g. equity, efficiency, ecological balance, etc.). They must therefore consider a wide range of policy objectives (implying a multidimensional goal function) to reflect the different aspirations and desires which exist within their community.

Thirdly, there is an increasing need to develop a flexible interregional framework, which permits certain linkages and spillover effects to be explored in greater detail. Important issues, such as energy consumption, environmental pollution, and resource depletion, now require specific treatment within an integrated economic framework. A few of the models in Table 3 have explored some of these issues. Other static models have examined the interactions between energy, pollution and other economic activities on a interregional basis (see Lesuis, Muller and Nijkamp 1980). An extension of the latter work into a dynamic setting would be extremely valuable.

Finally, but perhaps foremost, there is a formidable obstable which is shared by all the interregional modelling exercises undertaken so far: that of limited availability of suitable data. This difficulty seems likely to persist, as modellers attempt to introduce additional dimensions to the planning process. It is therefore important to make progressive changes and improvements to our methods of estimation. It is now clear that information theory can make an important contribution to this endeavour.

To build upon these earlier exercises, we shall now attempt to develop a general modelling framework which

(i) provides a flexible mechanism for the integrated analysis of national and regional development options, and also

(ii) demonstrates the valuable and versatile role which information theory can play in such an analysis.

5.3 A Hierarchical Modelling System

It is clear that long-term economic planning cannot be based on a single goal function alone, but must encompass a number of goals at different levels of the planning process. It must also allow for a mixture of variables, each of which may be determined or constrained at different levels. It therefore appears that wherever we wish to analyse organized economic activity, we are really confronted with multilevel or hierarchical phenomena.

Yet hierarchical analysis is still practically non-existent in traditional economic theory, and has only recently been introduced into regional science (see Isard 1977, Kaniss 1978, or Isard and Liossatos 1979). We shall try to consolidate on these few analyses, by describing a general hierarchical system which, for our present purposes, will consider only five different levels of modelling effort. This system has its foundations in Isard's globally balanced regional input-output model, which identifies a hierarchcal structure of political authorities and corresponding commodities (see Isard 1977).

Our multilevel system is depicted in Figure 1. Although it successively disaggregates the development problem, it also permits an autonomous tendency at each level to counterbalance the integrative forces in the system as a whole (see Koestler 1967, or Simon 1973). In reality, this hierarchy is open-ended in the downward, as it is in the upward direction.

The general system of models corresponding to this five-level hierarchy is represented in Figure 2. At the uppermost level, decisions taken concerning international trade patterns provide important constraints on feasible development options in each nation. Similarly, decisions taken at both the international and national levels impose further constraints on the decision-maker at the regional level. However, it should be stressed that higher-level models can only coordinate, but not completely control the goal-seeking activities at lower levels (Mesarovic et al. 1970).

We can associate this hierarchical structure of decision-making units with a simlar commodity classification system. It is not only useful, but increasingly necessry to recognize that some commodities are balanced (in terms of production and consumption) at the international level only. Others may be balanced at the national, regional or local levels. Similar distinctions are also made with respect to the mobility of industries (see Karlqvist et al. 1978). World industries (often referred to as transnationals or multinationals) are regarded as free to locate in any nation. National industries are free to locate in any region. World industries also tend to market their products to any nation, national

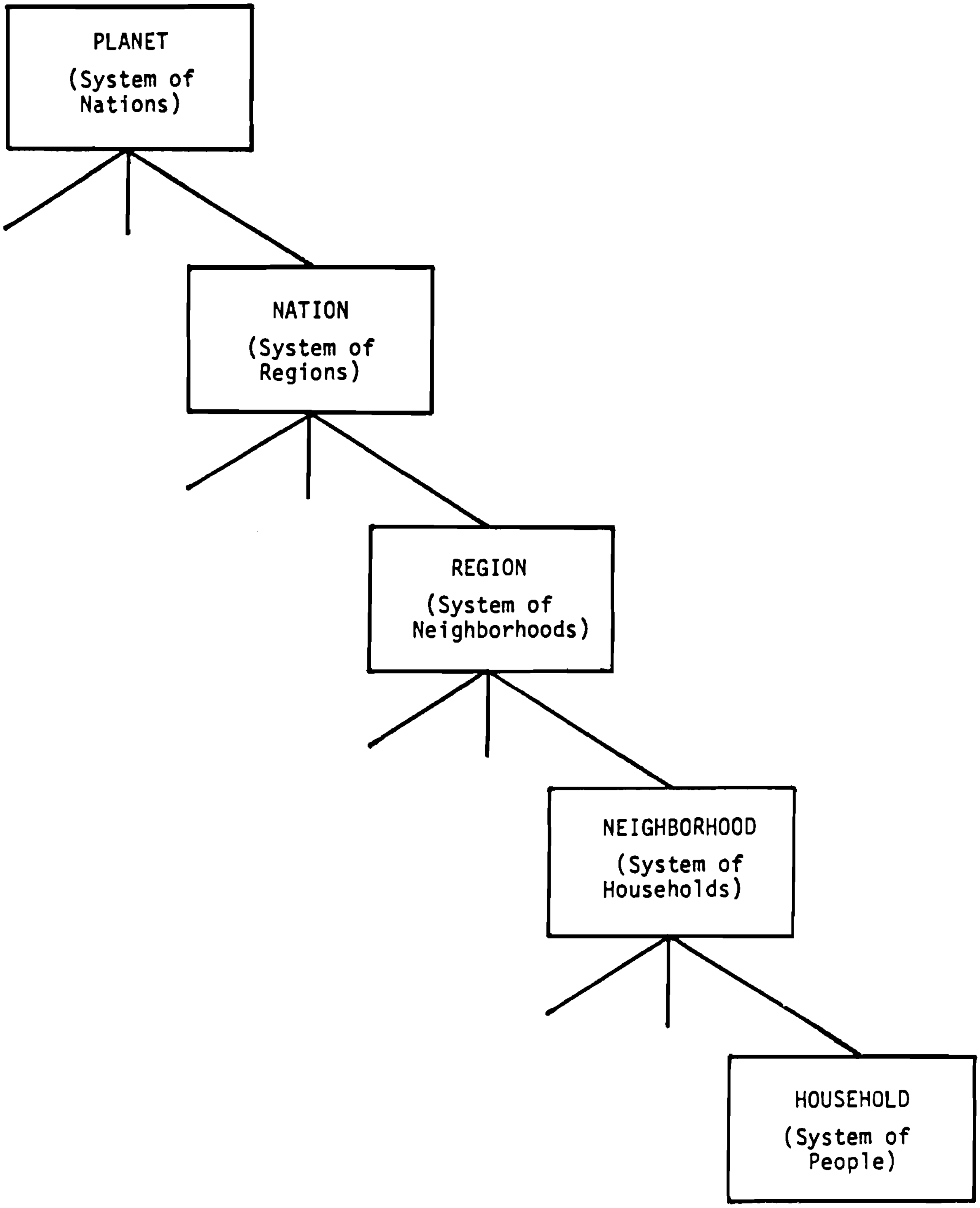

Figure 1. General multilevel social system.

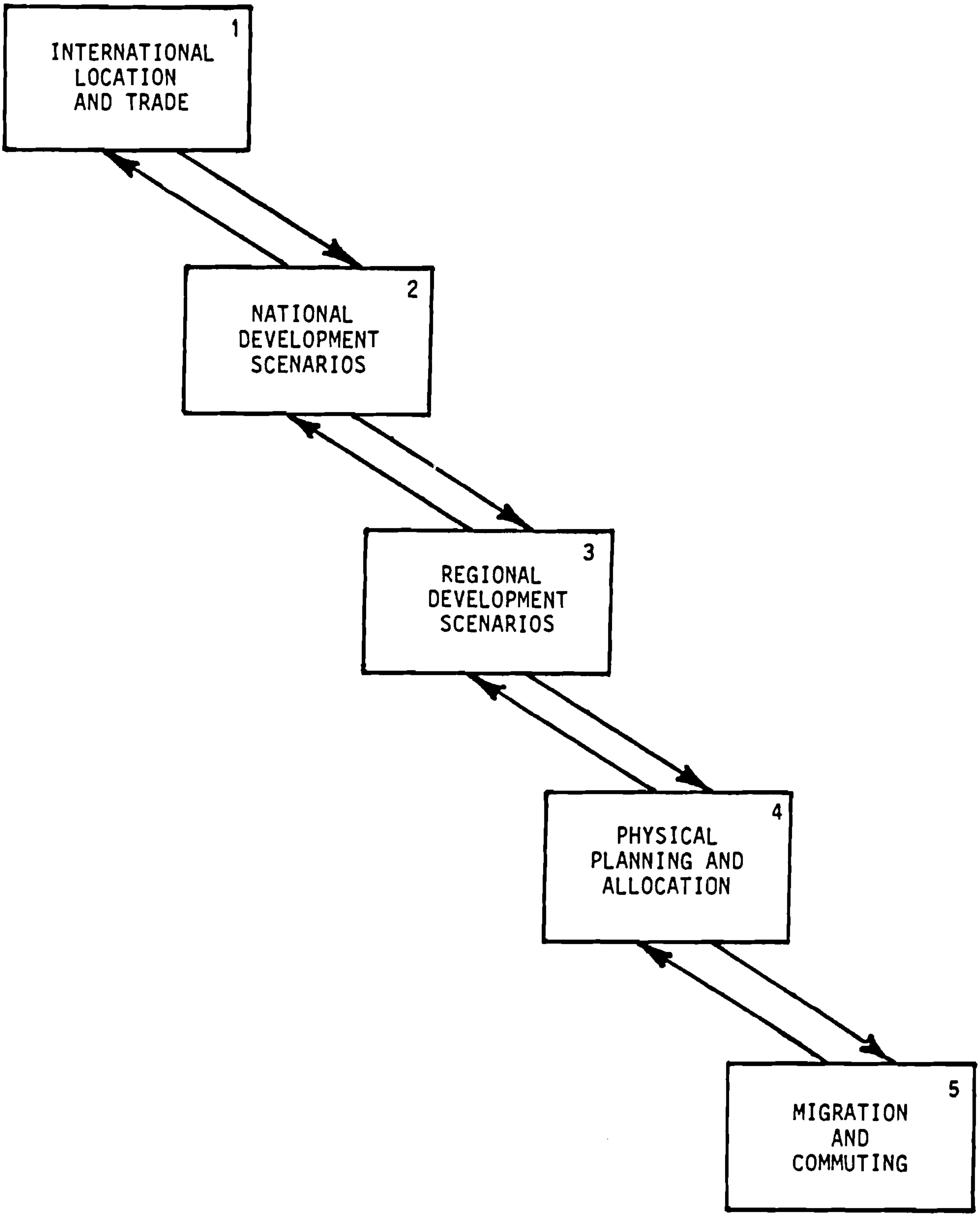

Figure 2. The hierarchical system of models.

industries to any region and so on. Which goods turn out to be world commodities, and which remain national, regional and local, depends to a large extent on the structure and conditions of trade.

The advantage of this five-level hierarchy lies in the ability to analyse each subsystem in a relatively independent fashion. The near-decomposability of subsystems (Simon 1973) makes it possible to focus on the dynamics of one level, while ignoring both higher and lower level dynamics for the sake of simplification. "We can build a theory of a system at the level of dynamics that is observable, in ignorance of the detailed structure of dynamics at the next level down." (Simon 1973, pp.110-117).

The autonomy permitted at each level is, of course, accompanied by a set of constraints to coordinate and integrate the submodels' behaviour. The control exerted through these constraints is closely related to the amount and type of information collected at each level. Simon's point is that near-decomposability minimizes information flows between levels, and hence between submodels. It is here that the first clue to the role which information theory could play in hierarchical systems analysis emerges.

As we move down our five-level hierarchy, at each step we progress to a model in which behaviour is increasingly disaggregated on a spatial basis. In so doing, we face an increasingly difficult data problem: that of making efficient use of the information furnished at higher, more aggregated levels, to coordinate the patterns of behaviour at the more disaggregated levels below. Information theory can obviously play a very useful role in our hierarchical modelling system.

We can also distinguish between the structural and functional aspects of this hierarchical system. Koestler relates the former to the spatial properties of the system, and the latter to processes over time (Koestler 1967, p.59). Evidently, structure and function are not easily spearated, and represent complementary aspects of an indivisible spatio-temporal process. By regarding each model (level) in our hierarchy as being responsible for a certain degree of detail, a separability of focus is maintained, leading to an efficient specialization of function at each level in the hierarchy.

An equilibrating function might be proposed for the national level. At the intermediate level of regional developments, a satisficing function is important, based on the need for compromise solutions. At even lower levels, where the decisions of individuals are more easily recognized, the logical function is one of optimization. Quite clearly, alternative functional arrangements would also warrant investigation.

5.4 Concluding Remarks

If we concentrate on the national and regional levels in our suggest modelling hierarchy, it is possible to devise a system of submodels which could be used to analyse feasible national and regional development options. Such an integrated system is schematically represented in Figure 3. It is certainly not considered to be the only instrument available for the analysis of feasible development paths in our spatial system. In reality, there is ample scope to modify the model formulations at each level, or even to discard the hierarchical assumption completely. It is left to the reader to ponder various alternative frameworks.

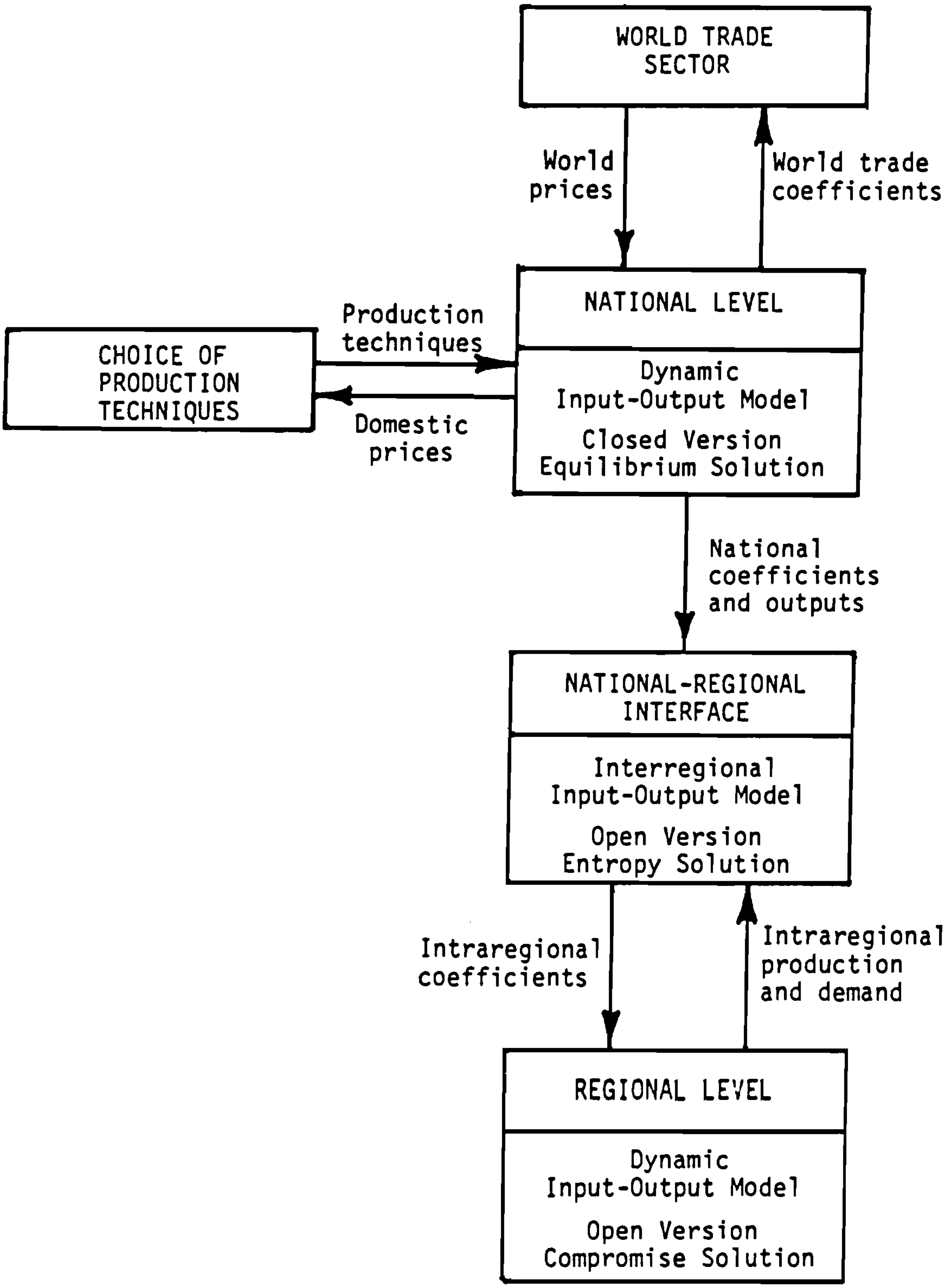

Figure 3. System of models for analysing feasible national and regional development options.

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