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To

Chairman (Research)
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Title of the report ....OPERATIONS RESEARCH IN NATIONAL AND MULTI-LEVEL PLANNING

Name of the Author ......Shishir K. Mukherjee.......................

Under which area do you like to be classified? ..Op. Research..

ABSTRACT (within 250 words)

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Please indicate restrictions if any that the author wishes to place upon this note Presented at the World Congress on Productivity Science for Progress of Mankind at Bombay during December 10-13, 1973.

Date 9-1-74........

Signature of the Author

OPERATIONS RESEARCH IN NATIONAL AND MULTI-LEVEL PLANNING

By
Shishir K. Mukherjee

January 1974

Indian Institute of Management
Ahmedabad 15

OPERATIONS RESEARCH IN NATIONAL AND MULTI-LEVEL PLANNING

A rapid increase in the productivity of all sectors is required in developing countries for the betterment of their people and removal of abysmal poverty. This may be achieved through the institution of planning at the national, sectoral and regional levels. Proper choice of projects to be included in the plan, their location and regional distribution play an important role in increasing the productivity of planned sectors of the economy and in the development of various regions. This paper discusses the application of operations research models in the dual hierarchial framework by regions and sectors of a national economy.

A class of computational techniques known as decomposition methods exhibit hierarchical problem structure quite similar to the multilevel planning problem. Detailed sectoral models or regional models involving project selection and spatial details could be integrated into a balanced national plan using such a planning and computational framework. An analysis of the various commodities produced would indicate the level at which project decisions for that commodity should be undertaken. The partial decomposition of the complex national problem makes planning more amenable to the application of operations research models for project selection and optimization.

Introduction

A rapid increase in the productivity of all sectors of the economy is a primary requirement in the developing countries in their struggle against poverty, hunger and overpopulation in trying to better the living standards of the masses. Proper planning of the economy and motivating the people will be necessary to make even modest achievements in this field. In the process of achieving a fast rate of growth in the gross national product (GNP) or average per capita income planning process should also bring about development of all the regions in a country in a balanced manner. It must provide for adequate resources for investments in the various sectors of the economy, determine appropriate growth targets in related sectors and ensure coordination among them, avoid shortages, bottlenecks and wastages and reduce regional imbalances as a result of development.

In a vast country like India, with a federal system of government and wide difference among its regions, planning should be simultaneously carried out at the national, sectoral and regional levels to achieve these objectives of planning. The process of planning and plan implementation also involves a hierarchy of institutions at the central, sectoral and regional levels. There could be serious short-coming in the planning process if all decisions regarding allocation of resources, investments and project selection are taken in a centralized top-down approach by the national planning agency and lower levels are directed to implement the planned projects. This is mainly because it is very difficult for the central planning agency to acquire complete and detailed information and expertise regarding all the sectors and regions of the country. The national planning agency usually prepares a highly aggregated national plan which does not consider the spatial aspects of planning including project selection and locational choices while these are highly essential in considering the economics and viability of the various alternatives in investment and also in the successful implementation of the plan. These decisions are usually taken at the lower echelons and in the absence of a proper multi-level planning framework, it is a difficult task to coordinate those interrelated decisions into an integrated national plan with sufficient details.

It is desirable to decompose the national planning problem by sectors and also by regions into manageable subproblems. The sectoral decomposition is necessary for detailed project formulation and project selection which should include a study of the spatial aspects such as transportation costs and locational decisions, the economic aspects such as choice of technology and economies-of-scale and the temporal aspects of time phasing and scheduling of projects. The regional decomposition would involve preparation of comprehensive development plans for the regions based on resource endowments, economic and other advantages of the regions and their social needs. Such plans should include project allocations for income and employment generation and provision of social infrastructure, the basic objectives of such plans being overall development and the regions and reduction of regional imbalances.

Optimal allocation of resources in such a "dual hierarchical system" is difficult to accomplish through the application of one comprehensive model specifically with any kind of spatial details or at the project level of disaggregation. The multi-level planning problem involving two or three hierarchical levels obtained by sectoral or regional decomposition assumes an added complexity as the sectoral and regional plans will have to be coordinated. The allocation of investments in a particular region by all the sectoral plans when combined together should result in a comprehensive regional plan. Conversely, allocations for any sector in plans for different regions should be optimal in some sense for that sector for the whole country and the growth of one sector should be in proper ratio to the growth of related sectors.

This is the central problem in multi-level planning. This paper discusses the application of operations research models in designing a multi-level planning framework by regions and sectors of a national economy. Operations research models have already found wide application in detailed sectoral planning work for a single[1,2] or for several interrelated sectors[3]. Techniques such as linear programming[4], dynamic programming[5] and network flow theory[6] have been applied in decision problems regarding size, location and nature of

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investment projects.[7] Programming models based on inter-industry tables are also quite common for national or regional planning. The challenge before us is to design a multi-level planning framework within which such sectoral and regional models could be interlinked and coordinated with any aggregated central level model available.

The application of a class of computational techniques known as decomposition methods is highly useful in this area as decomposition methods exhibit multi-level structure of programming problems and their solution techniques are based on information flow and iteration of problem solution between various hierarchical levels quite similar to the situation faced in multi-level planning. This approach will be examined later in the paper.

The complexity of the planning problem in the dual hierarchical multi-level system can be reduced considerably if the interlinkages between the sectors and regions are only partial, which indeed is the case. An analysis of the various commodities produced by a country indicates that the investment decisions regarding certain commodities could be taken at regional levels independent of the activities of the other regions as these decisions do not have appreciable effects outside the region in question. Again there are other commodities where investment decisions and their regional allocation must be arrived at by a central body for all the regions simultaneously. Following Tinbergen's[8] scheme all the commodities could be classified into regional or local products, national products and world products and again into shiftable or non-shiftable industries. Such classification gives an indication as to the industries or products to be included in regional, sectoral and national plans enabling us to obtain a decomposition of the multi-level planning model into various sub-models some of which are largely independent of higher level models could be solved in isolated and the solution fed into higher level models. This aspect of partial interlinkages between higher and lower level models have been examined later.

Balanced and Unbalanced Development

One of the important issue in regional planning is the

7. Eckaus, Richard S., and Kirit S. Parikh, Planning for Growth: Multi-Sectoral Intertemporal Models Applied in India, The MIT Press, Cambridge, Massachusetts, 1968.
8. Tinbergen, J., Essasy in Regional and World Planning, National Council of Applied Economic Research, New Delhi, July 1966, Chapter 11.

extent to which development should be geographically balanced or unbalanced. The qualitative arguments in favour of balanced and those against have been described by many authors. The analytical models[9,10,11] which try to arrive at any conclusions regarding the allocation of investments in a multi-region system are based on highly simplistic assumptions regarding consumption, savings and productivity of capital. Under these assumption they obtain the expected conclusion that if the objective is to maximize national income, then investments in less productive regions could only be justified under very rarely occuring situations such as when higher savings rate in the less productive region more than compensates for the low productivity of capital. But the basic question is not whether to invest in one region or the other, but in which proportion the available resources should be allocated. The dynamic aspects of the situation are also rarely considered in these models. A less productive region may also become equally productive as a highly productive region at least for the production of some commodities if certain initial investments are made in building the necessary infrastructure (transportation, power, etc.), service facilities and training of personnel. Again excessive concentration of investment in certain areas will raise the land price, increase wage rates and overtax the infrastructural facilities, as a result decreasing the productivity of capital in that area overa long period of time.

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9 Rahman, M.A., "Regional Allocation of Investment," Quarterly Journal of Economics, February, 1963, pp.26-39.

10 Dorfman, R., "Regional Allocation of Investment - Comment," Quarterly Journal of Economics, February, 1963, pp.162-65.

11 Bose, A.N., "Economic Development and Balanced Regional Growth," Indian Journal of Regional Science, Vol. I, No.1, 1968-69, pp. 37-52.

Commodity Classes and Locational Decisions

The above discussion leads us to another important issue - the effect of the nature of the commodity or service in question on its spatial location. Some commodities are comparatively footloose and can be located almost in any region without loss of productivity and that some are constrained to be located in certain regions. We follow Tinbergen[12] in dividing the commodities into three classes - world goods, national goods and regional (and local) goods. A regional commodity cannot be imported or exported from any region due to technical reasons (e.g. water resources project, buildings, local services). A national commodity or service cannot be exported or imported under normal circumstances the best examples being electricity and transportation. The world goods or commodities are free to cross international borders. The above division is market or transportation oriented. Similarly national or world commodities could be divided into shiftable (footloose) and nonshiftable commodities. A non-shiftable industry is resources or raw material based and can be located at the same region only, whereas a shiftable industry can be located in many different regions (e.g. electronics).

Under the division of commodities described above, one can have a better idea regarding the freedom available in the location of economic activities and the level in organizations where planning for these activities could be carried out. Obviously planning for regional commodities and services could be done best at the regional level and locational decisions regarding these will not have appreciable effects on other regions. The national commodities and services should be planned at the national level. As the locations of non-shiftable commodities (e.g. coal and other mining) are more or less determined by the availability of raw material and other constraints, one can play with shiftable commodities to obtain objectives of regional income targets if these are specified by the central planning agency. Transportation costs and economies-of-scale have important roles in determining the location of national goods and services. Preferably, detailed location-allocation models should be used to determine their regional distributions.

Operations Research Model for Central Planning

At the highest level of the multi-level planning system, a macro-economic dynamic model can be used at sectoral level of aggregation. If a state model is chosen, a long term perspective

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12 Tinbergen, J., op.cit,

plan should be available. The most recent input-output matrix available should be utilized for building the central level model. Linear programming structure based on an input-output matrix is quite suitable for the dynamic multi-sectoral model. Similar models have been extensively reported in the literature[13] and would not be discussed here in detail. Considering the acute unemployment situation in India, an additional feature of this model could be the inclusion of manpower requirements under different skill categories as an integral part of the model. Availability of foreign aid and upper limits on exports could be considered exogenously given to the model. However, certain import substitution activities could be considered and foreign exchange becomes an additional constraint in the model.

The multi-sectoral dynamic model should include at least two or more Five Year Plan periods and appropriate terminal conditions (such as growth at a constant rate beyond the terminal year). The planning horizon can be divided into a number of equal time periods each ranging between 2 and 4 years. Specific assumptions could be made regarding consumption, the simplest being the assumption of a gradualist consumption path (i.e., aggregate consumption growing at an annual rate r). In this case, the terminal consumption will be maximized. Alternatively, assumption of non-decreasing per capita consumption could be made and the sum of discounted GNP over the planning horizon is maximized. The main constraints of the resulting linear programming problem will be due to material balance, capacity, terminal conditions, exports, foreign exchange, labour demand and supply, consumption and savings. The detailed nature such a model could be decided upon based on the available numerical data, objectives of the model and its computational needs. The solution of the multi-sectoral linear programming model provides certain major guidelines regarding the order of magnitude of production and investment in various sectors. The dual solution of the linear programme would also generate shadow prices for the resources common to different sectors such as capital, labour, foreign exchange, etc.

If a two-level planning process is considered at the central and sectoral levels, the solution of the central level model can generate internally consistent time-wise projections of needed output for each sector and can provide shadow prices of factors allocated by the central planning agency among the

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13 Eckaus, Richard S., and Kirit S. Parikh, op. cit.

various sectors. The sectoral models should be formulated at project level considering locations, technological and capacity alternatives. The optimal solution of sectoral models for given sectoral demands provides improved technical coefficients such as incremental capital output ratios (ICOR), manpower and utility coefficients which can be used to update and modify the central level inter-industry matrix used. Thus an iterative scheme will improve the quality of both the models and their solutions after each iteration and information exchange. The process can be terminated after a few iterations and sectoral plans could be finalized.

The effect of various policy alternatives on the sectoral allocations could be studied using the multi-sectoral central level model. These might involve decisions regarding the amount of foreign aid, self reliance, export and import policies, choice between capital and labour-intensive technologies and other assumptions regarding savings, consumption and strategies for development. The shadow prices generated, to be useful in planning, should be stable and realistic. It is expected that a sufficiently long planning horizon will help in achieving this objective.

Spatial Sectoral Models for Project Selection

At the second level of the multi-level planning system, a class of sectoral models are conceived which encompass all the sectoral activities for the production of national and world commodities and services. Each sectoral model will be at the project or industry level of disaggretation, will consider substitution effects and make choices between alternative locations, technologies and capacities of projects. The selection of activities or products to be included in a particular sector and the decision regarding the total number of sectoral models requires considerable amount of judgement and knowledge of the economy. A common rule would be to group together strongly interrelated or substitutable activities or products within a single sector.

For certain sectoral activities, the sectoral model is the lowest level at which project decisions are made. For example the decision regarding investment in a new steel mill, its capacity, composition and location could be best decided within the framework of a model of the steel sector for the whole economy. If the optimal solution specifies a project to be located at a particular region, it could be included later in the regional model and would provide useful information regarding manpower and utility requirements and the advisability of locating anciliary and secondary industries in the region. But at the regional level (district or state level) model, it would be difficult to decide whether the steel mill should be included among the list of approved projects for the region.

For a better understanding of the composition of a sectoral model a representative sectoral model of the Energy sector[14] is briefly discussed here. A nationwide model of the energy sector can be formulated to analyse the production, distribution and consumption of various energy and fuel resources. This would include coal, petroleum and its products, electricity and nitrogeneous fertilizer. Demands for electricity, fertilizer, petroleum and its various products such as motor gasolene, naptha, kerosene, fuel oil, etc. and coal for other uses excluding production of power and nitrogenous fertilizer are given exogenously to the model. Spatial locations of these demands and their distribution at these demand centres are given inputs for the sectoral model. Production and transportation activities for coal, electricity, petroleum products and fertilizer are considered and locational, technological and size alternatives are analysed. Production of non-coking coal at various fields is considered in the Energy sector model whereas that of coking coal could be included in a sectoral model for steel. For electricity generation, hydro, thermal (coal, fuel oil, natural gas) and nuclear technologies will be compared.[15] Nitrogenous fertilizer should be included in the sectoral model for energy as it can use coal, naptha or fuel oil as feed stock and fuel. As importation of petroleum or its products induces foreign exchange expenditure, substitution activities of fuel oil and kerosene by coal or electricity would be included.

The objective function of the model would be minimization of total cost for satisfying all energy demands. Specific constraints could be included on the total capital investment and foreign exchange requirements of the resulting plan. These values will be supplied from the solution of the central level model. The shadow prices of capital or foreign exchange obtained from the solution of the sectoral model could be compared with those obtained from the solution of other sectoral models and the central level model. To obtain a realistic value of shadow price for capital, manpower con-

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14 Interim report (May 1972) of the Fuel Policy Committee, Ministry of Steel and Mines, Govt. of India.

15 Regional models for electricity sector is discussed in Mukherjee Shishir, K., op.cit.

straints should be included in sectoral models. As the sectoral model is at a project or industry level, it is easier to obtain manpower needs by skill categories from the project feasibility reports.

The detailed nature of the constraints for a sectoral model will depend on the nature of the sector and the policy questions to be asked by the model. The policy questions asked for a sectoral model are more related to the operations of the particular sector. In the Energy sectoral model described above, various policies regarding the pricing of petroleum and its products, optimal fertilizer production technology, coal-oil substitution, dieselisation as against electrification of railways and investments in oil exploration could be asked and from the quantitative answers obtained a rational energy policy would emerge. Similarly sectoral models in the area of Steel and Heavy Engineering, Agricultural and Water Resources and Transport could be formulated and their solution could provide answers to various policy questions which are not obvious from the central level studies.

Regional Planning Models

Regional planning models can serve two basic purposes. Their main use is in comprehensive planning for a region and in models of this kind all planned projects for the regional goods are included for combined project evaluation. These models can be constructed at the state or district level. Specifically a backward area or an area with high growth potential could be chosen for special attention. Structurally, the model is a linear programme for optimum project selection under constraints of regional demand, total investment, manpower and local resources (for resource based industries) and for maximizing the gross regional product (or total value added). The regional economy is open and there are usually no barriers to the flow of national or world goods and services according the market mechanism. These constraints will ensure that regional self-sufficiency is not aimed at a high cost for commodities which could be produced elsewhere and transported to the region to satisfy local demand. Constraints on employment needs of the region and minimum needs[16] for essential commodities could be imposed on the regional model. Thus a comprehensive regional plan based on socio-economic data (population and employment

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16 Planning Commission, Govt. of India, "Approach to the Fifth Plan, 1974-79," Section IV, January 1973.

could become a major vehicle for the implementation of development of the backward and not-so-backward regions promised in plan documents if resources could be provided for and appropriate implementation machinery set up.

Regional models are also useful to analyse detailed spatial or local aspects of sectoral plans as the inclusion of all details regarding a sector in the economy-wise sectoral plan might make it too large and unwieldy for computational purposes. For example, to supplement the sectoral energy model discussed in the last section, regional models of electricity generation and transmission could be formulated.[7] This model would include details of existing and proposed generating plants of different kinds and existing and proposed generating plants of different kinds and existing and proposed transmission lines. The optimal solution will provide a minimum-cost plan for regional power system. Structurally the model could be a mix i integer linear programme (to consider indivisibilities in project decision) or a net work programming model (to consider the transmission network in detail). Certain non-linearities could also be accomodated in this operations research model. To provide another example, a district level agricultural and irrigation model can be formulated. This will include various minor and major irrigation schemes, special cropping projects such as high-yield wheat, rice or cotton, multiple cropping patterns, agri-based industries, poultry, dairy and animal husbandry in a much greater detail than is possible in a sectoral model on agriculture.

The comprehensive regional planning models discussed earlier will communicate directly both with sectoral models (through shadow prices of commodities) and the central level model (through shadow prices of capital, etc.). But the regional planning model for a particular sector will only communicate with the corresponding sectoral model. Regional plans also illustrate the effects of planned projects on the population of the region in terms of growth in per capita of income and employment generated. These and other socio-economic indexes should be compared for various regions to ensure that regional inequities are not perpetuated. Otherwise, national averages of such indexes lose their meaning as they may not be representative of various regions of the country.

There has been increasing interest in the development of regional input-output tables and some pioneering work has been carried out for several states of India.[8] Though they

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7 Shishir K. Mukherjee, op.cit.

8 Alagh, Yoginder K., S.P. Kashyap, "Problems and Uses of Regional Input-Output Models," Anvesak, Vol.1, No.1, June, 1971.

present specific structure of regional economy, their utility in the preparation of regional plans are still limited specially in developing countries due to some of the inherent limitations of input-output analysis which become more noticeable at the regional level. For large country, the inter-regional flows are considerable and the treatment of national and world goods creates problems in regional input-output tables though for local or regional goods their use could be recommended.

Multi-level Planning Systems and Decomposition Procedure

We have discussed a proposal for decentralization of planning by constructing a hierarchy of model systems and a scheme of interaction between these models according to various interlinkages among these models. This is illustrated in the following diagram which shows the communication pattern between models at various levels. Decomposition procedures also discuss similar interactions and communication between problems at hierarchial levels. If all these models could be formulated and integrated at one place, (i.e. at the central planning level) perhaps the complex large system could be numerically solved by some kind of decomposition procedure. Even if these were possible, we are not proposing an interpretation of this kind of the proposed planning scheme as then it could hardly be called multi-level planning. We are interested in a planning procedure where sectoral and regional level organizations actually get involved in the decision-making and implementation of the planning process and the decomposition-like scheme of communication and iterations between models of various levels is utilized for coordinating their activities into an organic 'whole'.

Walras has described by "tatonnements", an iterative process by which the market finds its equilibrium. Against this we have the iterative schemes used for decomposition procedures where these are only steps within a computer and iterations do not effect the economy before an optimal solution is reached. Our proposed planning process will perhaps lie somewhere in between these two extremes. Only a few iterations could be performed before a periodic plan is decided upon and executed. These iterations will improve the solution of the total system though it may not reach the optimal solution. But action could not be stopped while a search for an optimum solution goes on. This difficulty is inherent in the operation of a decomposable organizational system as iterations in an organizational set up consume much more time and effort than they do in a computer. A similar scheme of planning using decomposition principle has been described by Dantzig[19] under "Central Planning without Complete Information at the Center."

19 Dantzig, George, B., Linear Programming and Extensions, Chapter 23, Princeton, N.J., Princeton University Press, 1963.

To appreciate the comments of the last paragraph, the reader should have some familiarity with decomposition procedures. The most well-known among them, the decomposition principle[20], was first proposed by Dantzig and Wolfe as a solution technique for large block-angular linear programming problems by decomposing them into smaller, more manageable sub-problems. Various other more recent approaches have been described by Geoffrion[21]. In a decomposition procedure the total problem is not solved at one step as done by the simplex method of linear programming. The problem is divided into a master problem and a number of sub-problems. The master *problem may not even be explicitly known at the beginning of* the computation. A simplex-like iteration is performed on the master problem to find an optimal solution and this generates a price vector (which may be interpreted as shadow prices) for the constraints of the master problem. The price vector defines objective functions for the sub-problems and they are then solved. Solution of the sub-problems generate new activities to be added to the master problem which then goes through another iteration. The solution process is terminated when no activities could be obtained from the solution of the sub-problem which can improve the solution of the master problem. The similarity between this procedure and the multi-level planning process where prices are used forc communication is obvious.

A different procedure for multi-level planning has also been reported in literature[22,23]. In this approach, the central level model allocates the scarce resources among sectors, i.e., determines input quotas and output targets. The sectors in turn send information to the central level regarding shadow prices for the scarce resources in an attempt to bid for them. It should be noted that the information content has changed here from our earlier convention of prices flowing downward and production plans upwards. Only practice will demonstrate if any of these systems could be utilized in the decision making processes of multi-level planning. We recommend that inspite of all the short-comings, multi-level planning should be practised, perhaps with its broader interpretation in the organizational sense.

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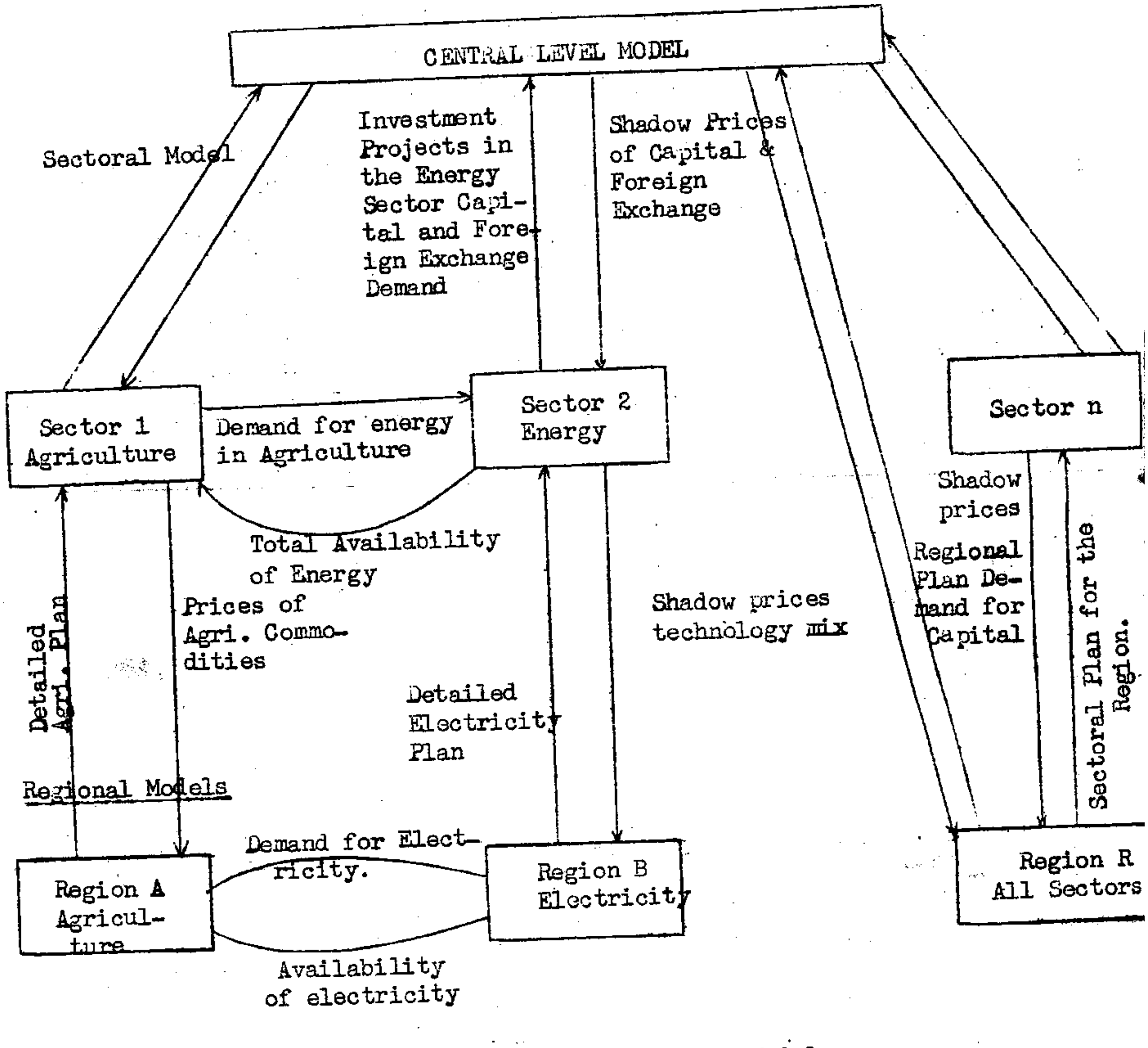
20 Dantzig, George, B., and Philip Wolfe, "Decomposition Principle for Linear Programs," Operations Research, Vol. 8, No.1, Jan. 1970.

21 Geoffrion, A., "Elements of Large-Scale Mathematical Programming," Management Science, Vol.16, No.11, July 1970.

22 Kornai, J., and Liptak, T., "Two Level Planning," Econometrica, 1965.

23 Weitzman, M., "Iterative Multi-level Planning with Production Targets," Econometrica, January 1970.



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investment projects. Programming models based on inter-industry tables[7] are also quite common for national or regional planning. The challenge before us is to design a multi-level planning framework within which such sectoral and regional models could be interlinked and coordinated with any aggregated central level model available.

The application of a class of computational techniques known as decomposition methods is highly useful in this area as decomposition methods exhibit multi-level structure of programming problems and their solution techniques are based on information flow and iteration of problem solution between various hierarchical levels quite similar to the situation faced in multi-level planning. This approach will be examined later in the paper.

The complexity of the planning problem in the dual hierarchical multi-level system can be reduced considerably if the interlinkages between the sectors and regions are only partial, which indeed is the case. An analysis of the various commodities produced by a country indicates that the investment decisions regarding certain commodities could be taken at regional levels independent of the activities of the other regions as these decisions do not have appreciable effects outside the region in question. Again there are other commodities where investment decisions and their regional allocation must be arrived at by a central body for all the regions simultaneously. Following Tinbergen's[8] scheme all the commodities could be classified into regional or local products, national products and world products and again into shiftable or non-shiftable industries. Such classification gives an indication as to the industries or products to be included in regional, sectoral and national plans enabling us to obtain a decomposition of the multi-level planning model into various sub-models some of which are largely independent of higher level models could be solved in isolated and the solution fed into higher level models. This aspect of partial interlinkages between higher and lower level models have been examined later.

Balanced and Unbalanced Development

One of the important issue in regional planning is the

7. Eckaus, Richard S., and Kirit S. Parikh, Planning for Growth: Multi-Sectoral Intertemporal Models Applied in India, The MIT Press, Cambridge, Massachusetts, 1968.
8. Tinbergen, J., Essasy in Regional and World Planning, National Council of Applied Economic Research, New Delhi, July 1966, Chapter 11.

extent to which development should be geographically balanced or unbalanced. The qualitative arguments in favour of balanced and those against have been described by many authors. The analytical models[9,10,11] which try to arrive at any conclusions regarding the allocation of investments in a multi-region system are based on highly simplistic assumptions regarding consumption, savings and productivity of capital. Under these assumption they obtain the expected conclusion that if the objective is to maximize national income, then investments in less productive regions could only be justified under very rarely occuring situations such as when higher savings rate in the less productive region more than compensates for the low productivity of capital. But the basic question is not whether to invest in one region or the other, but in which proportion the available resources should be allocated. The dynamic aspects of the situation are also rarely considered in these models. A less productive region may also become equally productive as a highly productive region at least for the production of some commodities if certain initial investments are made in building the necessary infrastructure (transportation, power, etc.), service facilities and training of personnel. Again excessive concentration of investment in certain areas will raise the land price, increase wage rates and overtax the infrastructural facilities, as a result decreasing the productivity of capital in that area over a long period of time.

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9 Rahman, M.A., "Regional Allocation of Investment." Quarterly Journal of Economics, February, 1963, pp.26-39.

10 Dorfman, R., "Regional Allocation of Investment - Comment," Quarterly Journal of Economics, February, 1963, pp.162-65.

11 Bose, A.N., "Economic Development and Balanced Regional Growth," Indian Journal of Regional Science, Vol. I, No.1, 1968-69, pp. 37-52.

Commodity Classes and Locational Decisions

The above discussion leads us to another important issue - the effect of the nature of the commodity or service in question on its spatial location. Some commodities are comparatively footloose and can be located almost in any region without loss of productivity and that some are constrained to be located in certain regions. We follow Tinbergen[12] in dividing the commodities into three classes - world goods, national goods and regional (and local) goods. A regional commodity cannot be imported or exported from any region due to technical reasons (e.g. water resources project, buildings, local services). A national commodity or service cannot be exported or imported under normal circumstances the best examples being electricity and transportation. The world goods or commodities are free to cross international borders. The above division is market or transportation oriented. Similarly national or world commodities could be divided into shiftable (footloose) and nonshiftable commodities. A non-shiftable industry is resources or raw material based and can be located at the same region only, whereas a shiftable industry can be located in many different regions (e.g. electronics).

Under the division of commodities described above, one can have a better idea regarding the freedom available in the location of economic activities and the level in organizations where planning for these activities could be carried out. Obviously planning for regional commodities and services could be done best at the regional level and locational decisions regarding these will not have appreciable effects on other regions. The national commodities and services should be planned at the national level. As the locations of non-shiftable commodities (e.g. coal and other mining) are more or less determined by the availability of raw material and other constraints, one can play with shiftable commodities to obtain objectives of regional income targets if these are specified by the central planning agency. Transportation costs and economies-of-scale have important roles in determining the location of national goods and services. Preferably, detailed location-allocation models should be used to determine their regional distributions.

Operations Research Model for Central Planning

At the highest level of the multi-level planning system, a macro-economic dynamic model can be used at sectoral level of aggregation. If a state model is chosen, a long term perspective

12 Tinbergen, J., op.cit.

plan should be available. The most recent input-output matrix available should be utilized for building the central level model. Linear programming structure based on an input-output matrix is quite suitable for the dynamic multi-sectoral model. Similar models have been extensively reported in the literature[13] and would not be discussed here in detail. Considering the acute unemployment situation in India, an additional feature of this model could be the inclusion of manpower requirements under different skill categories as an integral part of the model. Availability of foreign aid and upper limits on exports could be considered exogenously given to the model. However, certain import substitution activities could be considered and foreign exchange becomes an additional constraint in the model.

The multi-sectoral dynamic model should include at least two or more Five Year Plan periods and appropriate terminal conditions (such as growth at a constant rate beyond the terminal year). The planning horizon can be divided into a number of equal time periods each ranging between 2 and 4 years. Specific assumptions could be made regarding consumption, the simplest being the assumption of a gradualist consumption path (i.e., aggregate consumption growing at an annual rate r). In this case, the terminal consumption will be maximized. Alternatively, assumption of non-decreasing per capita consumption could be made and the sum of discounted GNP over the planning horizon is maximized. The main constraints of the resulting linear programming problem will be due to material balance, capacity, terminal conditions, exports, foreign exchange, labour demand and supply, consumption and savings. The detailed nature such a model could be decided upon based on the available numerical data, objectives of the model and its computational needs. The solution of the multi-sectoral linear programming model provides certain major guidelines regarding the order of magnitude of production and investment in various sectors. The dual solution of the linear programme would also generate shadow prices for the resources common to different sectors such as capital, labour, foreign exchange, etc.

If a two-level planning process is considered at the central and sectoral levels, the solution of the central level model can generate internally consistent time-wise projections of needed output for each sector and can provide shadow prices of factors allocated by the central planning agency among the

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13 Eckaus, Richard S., and Kirit S. Parikh, op. cit.

various sectors. The sectoral models should be formulated at project level considering locations, technological and capacity alternatives. The optimal solution of sectoral models for given sectoral demands provides improved technical coefficients such as incremental capital output ratios (ICOR), manpower and utility coefficients which can be used to update and modify the central level inter-industry matrix used. Thus an iterative scheme will improve the quality of both the models and their solutions after each iteration and information exchange. The process can be terminated after a few iterations and sectoral plans could be finalized.

The effect of various policy alternatives on the sectoral allocations could be studied using the multi-sectoral central level model. These might involve decisions regarding the amount of foreign aid, self reliance, export and import policies, choice between capital and labour-intensive technologies and other assumptions regarding savings, consumption and strategies for development. The shadow prices generated, to be useful in planning, should be stable and realistic. It is expected that a sufficiently long planning horizon will help in achieving this objective.

Spatial Sectoral Models for Project Selection

At the second level of the multi-level planning system, a class of sectoral models are conceived which encompass all the sectoral activities for the production of national and world commodities and services. Each sectoral model will be at the project or industry level of disaggretation, will consider substitution effects and make choices between alternative locations, technologies and capacities of projects. The selection of activities or products to be included in a particular sector and the decision regarding the total number of sectoral models requires considerable amount of judgement and knowledge of the economy. A common rule would be to group together strongly interrelated or substitutable activities or products within a single sector.

For certain sectoral activities, the sectoral model is the lowest level at which project decisions are made. For example the decision regarding investment in a new steel mill, its capacity, composition and location could be best decided within the framework of a model of the steel sector for the whole economy. If the optimal solution specifies a project to be located at a particular region, it could be included later in the regional model and would provide useful information regarding manpower and utility requirements and the advisability of locating anciliary and secondary industries in the region. But at the regional level (district or state level) model, it would be difficult to decide whether the steel mill should be included among the list of approved projects for the region.

For a better understanding of the composition of a sectoral model a representative sectoral model of the Energy sector[14] is briefly discussed here. A nationwide model of the energy sector can be formulated to analyse the production, distribution and consumption of various energy and fuel resources. This would include coal, petroleum and its products, electricity and nitrogeneous fertilizer. Demands for electricity, fertilizer, petroleum and its various products such as motor gasolene, naptha, kerosene, fuel oil, etc. and coal for other uses excluding production of power and nitrogenous fertilizer are given exogenously to the model. Spatial locations of these demands and their distribution at these demand centres are given inputs for the sectoral model. Production and transportation activities for coal, electricity, petroleum products and fertilizer are considered and locational, technological and size alternatives are analysed. Production of non-coking coal at various fields is considered in the Energy sector model whereas that of coking coal could be included in a sectoral model for steel. For electricity generation, hydro, thermal (coal, fuel oil, natural gas) and nuclear technolggies will be compared.[15] Nitrogenous fertilizer should be included in the sectoral model for energy as it can use coal, naptha or fuel oil as feed stock and fuel. As importation of petroleum or its products induces foreign exchange expenditure, substitution activities of fuel oil and kerosene by coal or electricity would be included.

The objective function of the model would be minimization of total cost for satisfying all energy demands. Specific constraints could be included on the total capital investment and foreign exchange requirements of the resulting plan. These values will be supplied from the solution of the central level model. The shadow prices of capital or foreign exchange obtained from the solution of the sectoral model could be compared with those obtained from the solution of other sectoral models and the central level model. To obtain a realistic value of shadow price for capital, manpower con-

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14 Interim report (May 1972) of the Fuel Policy Committee, Ministry of Steel and Mines, Govt. of India.

15 Regional models for electricity sector is discussed in Mukherjee Shishir, K., op.cit.

straints should be included in sectoral models. As the sectoral model is at a project or industry level, it is easier to obtain manpower needs by skill categories from the project feasibility reports.

The detailed nature of the constraints for a sectoral model will depend on the nature of the sector and the policy questions to be asked by the model. The policy questions asked for a sectoral model are more related to the operations of the particular sector. In the Energy sectoral model described above, various policies regarding the pricing of petroleum and its products, optimal fertilizer production technology, coal-oil substitution, dieselisation as against electrification of railways and investments in oil exploration could be asked and from the quantitative answers obtained a rational energy policy would emerge. Similarly sectoral models in the area of Steel and Heavy Engineering, Agricultural and Water Resources and Transport could be formulated and their solution could provide answers to various policy questions which are not obvious from the central level studies.

Regional Planning Models

Regional planning models can serve two basic purposes. Their main use is in comprehensive planning for a region and in models of this kind all planned projects for the regional goods are included for combined project evaluation. These models can be constructed at the state or district level. Specifically a backward area or an area with high growth potential could be chosen for special attention. Structurally, the model is a linear programme for optimum project selection under constraints of regional demand, total investment, manpower and local resources (for resource based industries) and for maximizing the gross regional product (or total value added). The regional economy is open and there are usually no barriers to the flow of national or world goods and services according the market mechanism. These constraints will ensure that regional self-sufficiency is not aimed at a high cost for commodities which could be produced elsewhere and transported to the region to satisfy local demand. Constraints on employment needs of the region and minimum needs[16] for essential commodities could be imposed on the regional model. Thus a comprehensive regional plan based on socio-economic data (population and employment

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16 Planning Commission, Govt. of India, "Approach to the Fifth Plan, 1974-79," Section IV, January 1973.

could become a major vehicle for the implementation of development of the backward and not-so-backward regions promised in plan documents if resources could be provided for and appropriate implementation machinery set up.

Regional models are also useful to analyse detailed spatial or local aspects of sectoral plans as the inclusion of all details regarding a sector in the economy-wise sectoral plan might make it too large and unwieldy for computational purposes. For example, to supplement the sectoral energy model discussed in the last section, regional models of electricity generation and transmission could be formulated.[17] This model would include details of existing and proposed generating plants of different kinds and existing and proposed generating plants of different kinds and existing and proposed transmission lines. The optimal solution will provide a minimum-cost plan for regional power system. Structurally the model could be a mixed integer linear programme (to consider indivisibilities in project decision) or a net work programming model (to consider the transmission network in detail). Certain non-linearities could also be accomodated in this operations research model. To provide another example, a district level agricultural and irrigation model can be formulated. This will include various minor and major irrigation schemes, special cropping projects such as high-yield wheat, rice or cotton, multiple cropping patterns, agri-based industries, poultry, dairy and animal husbandry in a much greater detail than is possible in a sectoral model on agriculture.

The comprehensive regional planning models discussed earlier will communicate directly both with sectoral models (through shadow prices of commodities) and the central level model (through shadow prices of capital, etc.). But the regional planning model for a particular sector will only communicate with the corresponding sectoral model. Regional plans also illustrate the effects of planned projects on the population of the region in terms of growth in per capita of income and employment generated. These and other socio-economic indexes should be compared for various regions to ensure that regional inequities are not perpetuated. Otherwise, national averages of such indexes lose their meaning as they may not be representative of various regions of the country.

There has been increasing interest in the development of regional input-output tables and some pioneering work has been carried out for several states of India.[18] Though they

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17 Shishir K. Mukherjee, op.cit.

18 Alagh, Yoginder K., S.P. Kashyap, "Problems and Uses of Regional Input-Output Models," Anvesak, Vol.1. No.1 June, 1971

present specific structure of regional economy, their utility in the preparation of regional plans are still limited specially in developing countries due to some of the inherent limitations of input-output analysis which become more noticeable at the regional level. For large country, the interregional flows are considerable and the treatment of national and world goods creates problems in regional input-output tables though for local or regional goods their use could be recommended.

Multi-level Planning Systems and Decomposition Procedure

We have discussed a proposal for decentralization of planning by constructing a hierarchy of model systems and a scheme of interaction between these models according to various interlinkages among these models. This is illustrated in the following diagram which shows the communication pattern between models at various levels. Decomposition procedures also discuss similar interactions and communication between problems at hierarchial levels. If all these models could be formulated and integrated at one place, (i.e. at the central planning level) perhaps the complex large system could be numerically solved by some kind of decomposition procedure. Even if these were possible, we are not proposing an interpretation of this kind of the proposed planning scheme as then it could hardly be called multi-level planning. We are interested in a planning procedure where sectoral and regional level organizations actually get involved in the decision-making and implementation of the planning process and the decomposition-like scheme of communication and iterations between models of various levels is utilized for coordinating their activities into an organic 'whole'.

Walras has described by "tatonnements", an iterative process by which the market finds its equilibrium. Against this we have the iterative schemes used for decomposition procedures where these are only steps within a computer and iterations do not effect the economy before an optimal solution is reached. Our proposed planning process will perhaps lie somewhere in between these two extremes. Only a few iterations could be performed before a periodic plan is decided upon and executed. These iterations will improve the solution of the total system though it may not reach the optimal solution. But action could not be stopped while a search for an optimum solution goes on. This difficulty is inherent in the operation of a decomposable organizational system as iterations in an organizational set up consume much more time and effort than they do in a computer. A similar scheme of planning using decomposition principle has been described by Dantzig[19] under "Central Planning without Complete Information at the Center."

19 Dantzig, George, B., *Linear Programming and Extensions*, Chapter 23, Princeton, N.J., Princeton University Press, 1963.

To appreciate the comments of the last paragraph, the reader should have some familiarity with decomposition procedures. The most well-known among them, the decomposition principle[20], was first proposed by Dantzig and Wolfe as a solution technique for large block-angular linear programming problems by decomposing them into smaller, more manageable sub-problems. Various other more recent approaches have been described by Geoffrion[21]. In a decomposition procedure the total problem is not solved at one step as done by the simplex method of linear programming. The problem is divided into a master problem and a number of sub-problems. The master problem may not even be explicitly known at the beginning of the computation. A simplex-like iteration is performed on the master problem to find an optimal solution and this generates a price vector (which may be interpreted as shadow prices) for the constraints of the master problem. The price vector defines objective functions for the sub-problems and they are then solved. Solution of the sub-problems generate new activities to be added to the master problem which then goes through another iteration. The solution process is terminated when no activities could be obtained from the solution of the sub-problem which can improve the solution of the master problem. The similarity between this procedure and the multi-level planning process where prices are used forc communication is obvious.

A different procedure for multi-level planning has also been reported in literature[22,23]. In this approach, the central level model allocates the scarce resources among sectors, i.e., determines input quotas and output targets. The sectors in turn send information to the central level regarding shadow prices for the scarce resources in an attempt to bid for them. It should be noted that the information content has changed here from our earlier convention of prices flowing downward and production plans upwards. Only practice will demonstrate if any of these systems could be utilized in the decision making processes of multi-level planning. We recommend that inspite of all the short-comings, multi-level planning should be practised, perhaps with its broader interpretation in the organizational sense.

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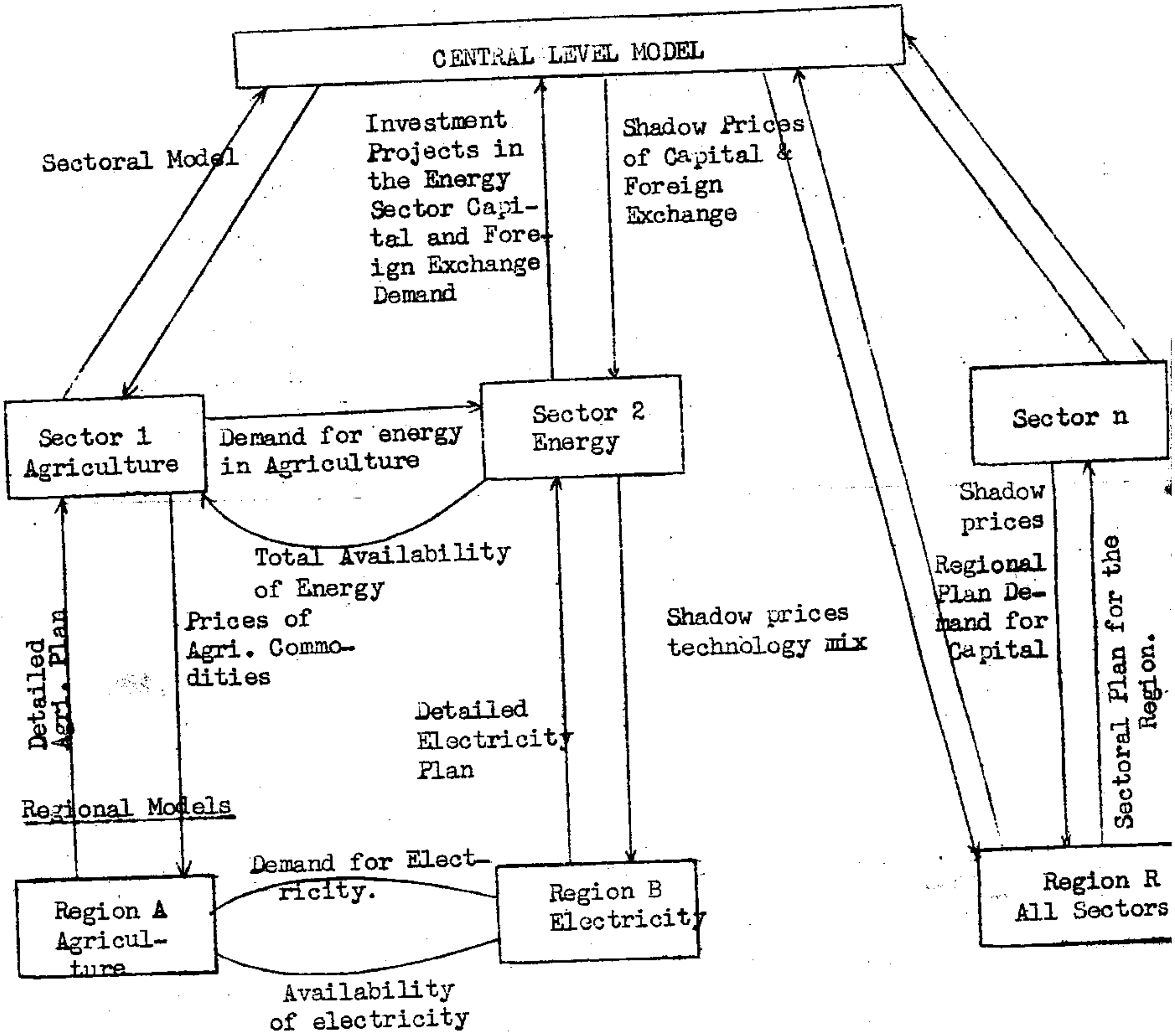
20 Dantzig, George, B., and Philip Wolfe, "Decomposition Principle for Linear Programs," Operations Research, Vol. 8, No.1, Jan. 1970.

21 Geoffrion, A., "Elements of Large-Scale Mathematical Programming," Management Science, Vol.16, No.11, July 1970.

22 Kornai, J., and Liptak, T., "Two Level Planning," Econometrica, 1965.

23 Weitzman, M., "Iterative Multi-level Planning with Production Targets," Econometrica, January 1970.



Multi-Level Planning Models