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Date August 28, 1985

WORLD MODELS AND PLANNING

A Thesis
Presented for the
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Degree
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Barbara Booker Pritchard

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This thesis is lovingly dedicated

to my parents,

J. Robert and Jean I. Booker,

for teaching me the importance of

compassion, faith in mankind,

and peace.

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ABSTRACT

World modeling is a rather new approach to forecasting the future trends of the complex systems that exist in our world. Therefore, it has a great deal to offer to policy-makers and planners in planning for the future. However, two problems exist with world models and their use in the planning world. The first of these problems stems from the fact that existing world models are in need of review and updating. The secondary problem relates to the lack of use of world modeling in the planning profession.

This thesis examines and compares the results of three world models. Suggestions are then given for areas of the models to be updated. Finally, suggestions are made for the use of world models in national planning, educational institutions, and multinational corporations.

The finding of this study is that the world system is a complex mix of activities needing direction and guidance. World modeling is shown to be a valuable planning tool for examining and forecasting present trends and the implications of future policy-making on the world system.

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CHAPTER 1

INTRODUCTION

The Beginning of World Modeling

> Man has skyrocketed from a defensive position, largely subordinated to Nature's alternatives, to a new and dominant one. From it, he not only can and does influence everything else in the world but, voluntarily or unwittingly, can and indeed does determine the alternatives of his own future--and ultimately must choose his options for it. In other words, his novel power condition practically compels him to take up altogether new regulatory functions that willy-nilly he has to discharge with respect to the world's mixed natural-human systems. Having penetrated a number of the erstwhile mysteries and being able to sway events so massively, he is now vested with unprecedented, tremendous responsibilities and thrown into the new role of moderator of life on the planet--including his own life. (Peccei, 1977, p. 21)

The above words were written by an Italian economist and businessman, Aurelio Peccei. Peccei began to realize early in his careers with Fiat, Olivetti, and Italconsult (an engineering and economic consulting agency) that all the individual projects and programs he was involved with were in vain when placed in the deteriorating context in which they were embedded--namely the global world condition. Peccei felt compelled to attempt to do something to stop the world's progress at its present haphazard pace and help to provide some direction.

In 1967, Peccei met Alexander King, the then Director General for Scientific Affairs of the Organization for Economic Cooperation and Development. It was soon apparent to both men that their feelings about the world predicament and the need to do something about it were the same. They decided to approach other scientists, economists, sociologists, and planners who seemed to have broad views of the world. In order to reach these people, Peccei and King decided that a background paper on the subject was necessary. The paper was written and sent to thirty learned people asking them all to meet in Rome, April 6 and 7, 1968, to discuss the issues.

All in all, as Alexander King said, "this meeting was a monumental flop" (Peccei, 1977, p. 65). There were too many problems with semantics among the different languages. There were also basic debates over theological foundations that raised more questions then answers. It was impossible to get the group to agree on anything, much less suggest possible prescriptions for the world's problems. However, a small core of individuals, deciding that the issue was too important to be dismissed, refused to be defeated. This core became a continuing committee, naming themselves the Club of Rome after the place where they had all first met.

In its subsequent meetings, the Club of Rome came to describe the world situation as the problematique. It was defined as (Hughes, 1980):

> a complex of interrelated problems: the recent growth and apparent persistence of a major gap in living standard between the richest and poorest people; the shrinking nonrenewable resource base of the globe; the increasing interrelatedness of issue areas once perceived to be self contained; mankind's ever growing ability to affect its larger environment in frequently unanticipateed and undesirable ways; and the inability of current social and political institutions to deal with these problems. (p. 1)

With this working definition for the world situation, the Club of Rome then came to the consensus that the best way to present the problematique would be through the systematic use of world models. They subsequently commissioned a series of multiple-issue world simulations. Two of these were World2 and its improved version, World3, by Jay Forrester and Dennis Meadows, and the World Integrated Model by Mihajlo Mesarovic and Eduard Pestel. Following these models, the United Nations, in 1972, asked Wassily Leontief to construct a world economy model.

The History of World2 and World3

Jay Forrester became involved with the Club of Rome in June 1970. It was then that he informed them that he had been working on a world simulation model and would have it ready to show them in a short period of time. Exactly four weeks later, Forrester presented to the Club of Rome a rough but comprehensive world model, along with the results from some preliminary test runs on the computer. The model was dubbed World1. The preliminary runs identified several errors and misconceptions. The model was reformulated and renamed World2. The Club of Rome decided that his model was worthy of further development. At the request of Forrester, Dennis L. Meadows, a young assistant of Forrester's, was asked to lead a team to further improve on World2. The resulting model became World3.

Methodology. Forrester and Meadows both designed their models using system dynamics. Both men believed that the interrelationships among the various systems of our society were just as important if not more important than the inner workings of each individual system. The system dynamics approach best suited their beliefs. Unlike most mathematical models, the system dynamics model accepts multiple-feedback-loops and nonlinear factors. Multiple-feedback-loops are made up of cause-and-effect chains which close on themselves in such a way that if one element in the chain is increased all elements along the chain will be changed until the effect comes full ciricle back to the original element which is increased even further (Hughes, 1980).

Structure. World2 consists of five main interdependent parameters: (1) population, (2) capital investment, (3) usuage of nonrenewable resources, (4) pollution, and (5) food production. Forrester quantified these parameters with existing data from several different sources. In order to determine the impacts of one of these systems on another, Forrester selected probable ranges of interactions. The model also lumped all nations into a single unit. There is no breakdown between developed or undeveloped countries.

World3 also considers the world in one large geographical unit. However, it differs from World2 in its main parameters. World3 consists of five major components: (1) the economy (divided into three sections), (2) population (divided into four cohorts), (3) agriculture, (4) resources (including all energy and nonenergy resources), and (5) environment. Both World2 and World3 have a time horizon of 1900-2100 (Meadows et al., 1974).

The History of the World Integrated Model

Mihajlo Mesarovic and Eduard Pestel are both systems analysts and original members of the Club of Rome. Their model was inspired by the same motives and ideals that were behind World2 and World3. The Club of Rome supported their model in order to further the Club's study of the world problematique. The structure and results of the World Integrated Model (WIM) are found in their book Mankind at the Turning Point (1974).

Methodology. The WIM is based on hierarchical systems theory. Both Mesarovic and Pestel agreed with Forrester and Meadows that the world's social systems are too complex to be handled by unaided human intuition. However, unlike Forrester and Meadows, they felt this was true because of the hierarchical nature of the various systems. WIM views the world as a complex of five interrelated planes arranged in the following descending order: (1) individual, (2) group, (3) demographic/economic, (4) technology, and (5) environment. Each of these strata operates with a degree of autonomy. However, when a "crisis" period occurs, the stratum become highly interrelated resulting in a flow of interactions.

Structure. The WIM consists of a number of submodels. These subunits include: (1) economy (divided into seven sectors), (2) population, (86 cohorts), (3) energy (five categories), (4) food (five categories), (5) materials (three categories), (6) labor/education (four categories), (7) machinery, (8) aid/loans, (9) trade (15 categories), and (10) relative prices. Mesarovic and Pestel considered these areas across ten geographical regions: (1) North America, (2) Western Europe, (3) Pacific Developed Countries, (4) the rest of the Developed

World, (5) Eastern Europe and the Soviet Union, (6) Latin America, (7) Middle East and North Africa, (8) Africa, (9) South and Southeast Asia, and (10) China. Later the areas were reconsidered and the original South and Southeast Asia Region was divided into Middle East Oil Producers and Nonoil Producing Arab Countries. The original South and Southeast Asia Region was also divided into Southeast Asia (including Indonesia), and South Asia (including primarily India, Pakistan, and Bangladesh). These changes brought the number of geographic regions to a total of twelve. The time horizon for the WIM is 1975-2025 (Mesarovic & Pestel, 1974).

The History of the United Nations Model

In 1972 the United Nations (UN) asked Wassily Leontief to develop a world model. In response to the International Development Strategy adopted by the UN General Assembly in 1970, the UN was searching for empirical data in its examination of the present international economic order. They wished to determine whether the economic targets set in the above strategy could be threatened by the physical limitations of the earth. Leontief began to work in 1972 on the model with a group of other interested and talented individuals from Brandeis and Harvard Universities. The results of the work can be found in their book The Future of the World Economy (1977).

Methodology. The UN model is based on input-output analysis. Unlike the aforementioned models, this model is extremely mathematical, reducing everything into a quantifiable measure. Basically, the model is a large system of simultaneous linear equations with more unknowns than equations. The number of equations is made equal to the number of unknowns by solving the system of equations by using specified values from outside sources for key variables. These variables and some of the equations' coefficients are then projected into the future to the year 2000 in five year increments at which point the system is solved again.

Structure. The UN model contains three substantive areas of analysis. One area is the economy which is divided into 48 input-output sectors, more specifically four sectors for food, nine sectors for minerals/energy, 22 sectors for manufacturing, and eight sectors for pollutants. The second area is trade which consists of 40 categories, and the final area is relative prices. Geographicaly the UN model is divided into three regions: (1) Developed, (2) Developing Group I (developing with major mineral resource endowment), and (3) Developing Group II. The Developed Region consists of eight areas of the world while the Developing Group I and Developing Group II consist of three and four areas respectively. The time horizon on this model is 1970-2000 in ten year increments (Leontief et al., 1977).

Problem Statement

The models mentioned above are considered to be among the more complex and complete world models available today. All have provided startling results of where the world is headed given certain trends and assumptions. They all have a great deal to offer to policy-makers and planners in planning for our future. However, two very real problems exist with world models and their use in the planning world. The first of these problems stems from the fact that there are limitations to all world models. Some of these limitations are inherent in the modeling process itself or the methodology employed. Other limitations are the result of the fact that these models were originally developed in the early 1970s. The world problematique has changed and taken on many different dimensions and directions since that time. In order to be useful world models need to be periodically reviewed and updated to accurately describe the new environment.

A secondary problem relates to the lack of use of world modeling in the planning profession. This study will touch on this issue by attempting to illuminate various ways in which world models may be used in order to aid in making policy decisions. While it is recognized that this second problem area is of considerable importance, it is essential to understand world models and their limitations and capabilities in order to assess their place in the planning environment. Therefore, the main emphasis of this study is on the nature and structure of world models, their deficiences and problems, and suggestions for updating and improvement.

Methodology

The methodology of this study is descriptive and comparative in nature. A historical review of world modeling and the three specific models to be compared will be provided to introduce the reader to the subject area. The three models will then be examined separately, detailing the methodology, structure, and results of each. The results of the models will then be compared summarizing major similarities and differences. Finally the models will be viewed in light of today's world situation and recommendations given for some modifications needed to make them applicable today.

Need for the Study

The Bureau of the Census has estimated that in the year 2000 there will be 6.35 billion people inhabiting the earth. That is 1.47 billion people more than in the year 1985 (Council on Environmental Quality and the Department of State, 1980, p. 8). It is crucial that the present world population plan for these additional individuals on a planet that is running out of the food, energy, and land that they will need in order to survive. World models can be important tools in the search for solutions for the world problematique. Therefore, it is important that they be understood and constantly reviewed and updated in order to provide relevant information and direction in today's world. This study will do just that and provide a dicussion of the significance of these models for the planning profession. It is hoped that the awareness and understanding of world modeling will provide planners with the skills and information necessary to not only address the world problematique but to also aid in the constant review and updating of these models.

Organization of Thesis

This thesis is organized in order to first provide background information on world modeling and the three aforementioned models in particular. The capabilities and limitations of world modeling are discussed along with the possibilities for the use of world models in planning.

Chapter 2 examines the models World2 and World3 developed by Forrester and Meadows. The first section of the chapter covers the methodology used in the models. This is followed by a discussion of the structure and general results of the models.

Chapter 3 is a detailed description of the World Integrated Model developed by Mesarovic and Pestel. The methodology used to develop the model is discussed in the first part of the chapter. This is followed by an explanation of the structure and results of the model.

Chapter 4 examines the United Nations world model developed by Leontief. The methodology of the model is discussed in the first section of the chapter. The structure and results of the model are also discussed in subsequent sections.

Chapter 5 consists of a comparison of the results of the output of the "basic" runs of these three models. The specific runs were selected as those made based on assumptions that project current trends on into the future. The similarities and differences in model output are also discussed.

Chapter 6 outlines the limitations of world modeling. Recommendations are also given as to how some of these limitations can be eleviated. The possible role of world models in planning is also discussed.

Finally, Chapter 7 summarizes the theme of this work and reviews the area of world models and their place in the planning environment. Included in this chapter is a section identifying other areas of world modeling that are in need of research. Other suggested areas of research include the role of social institutions and their abilities to use world models.

CHAPTER 2

WORLD2 AND WORLD3

Methodology of System Dynamics Models

World2 and World3 are both system dynamics models. System dynamics methodology was developed primarily by Jay Forrester. Most of the group that developed World3 studied under Forrester at the Massachusetts Institute of Technology. The foundations of system dynamics were laid at MIT beginning in the 1930s with the work of three individuals. Vannevar Bush built a differential analyzer to solve the equations of certain engineering problems. The equations made up a model of the system they represented. This model, in effect, described the rules that govern the systems behavior. Therefore, the differential analyzer acted as a simulator to trace the dynamic behavior of the system being studied. The second contributor to early system dynamics thought was Norbert Weiner who developed the concept of feedback systems which was later called "cybernetics." Harold L. Hazen was the last contributor during the 1930s. He wrote some of the first introductory papers in the field of feedback control that was to be known as "servomechanisms." During the 1940s, Gordon S. Brown created the Servomechanisms Laboratory in which the theory of feedback systems was expanded, recorded, and taught. Finally, Jay Forrester entered the area of study in the 1950s. He was then the Director of the Digital Computer Laboratory and Division 6 of the Lincoln Laboratory where digital computers were first used for system simulators. Since 1956, Forrester in conjunction with his associates at the MIT Alfred P. Sloan School of Management, has expanded the study of systems to greater and more complex social systems.

Basically, system dynamics theory recognizes that the structure of any given system is often just as important in determining its behavior as the individual components involved. A system dynamics model is a theory of how change occurs in a social or economic system. This process of change is described through a set of simultaneous first-order differential or integral equations. However, this methodology differs from that of simultaneous-equation models (such as the UN model) by the fact that system dynamics models assume that change in social systems occurs through the process of integration. Simultaneous-equation models, on the other hand, describe equilibrium rather than intertemporal relationships and limit the changes in internal system variables to those which occur only as the result of a change in exogenous variables.

Its use of simultaneous first order equations is not the only component that makes system dynamics models different from other global models. Another unique factor of these models is that they emphasize the inclusion of nonmeasured variables, operational meaning (as opposed to abstract or statistical), and robustness under extreme conditions. It is just these factors, however, that tend to make this type of model appealing to nonacademic groups due to the lack of abstract theory and the use of familiar terminology and recognizable interaction of processes.

System dynamicists use nonlinear functional relationships in order to use operational variables and to construct models that will not break down under extreme conditions or outside the range of observed system behavior. In functional relationships, it is common for extreme conditions to lead to a point of increasing or diminishing returns. In effect, in many situations things can only be carried so far before there is a change in the way the system responds. In a system dynamics model such functional situations are transposed into nonlinear functional relationships. For example, if told that within a given system not much happens past a certain point when one increases a certain input, the modeler would be likely to draw a curve of diminishing returns around that point. The system dynamicist, however, would transpose the situation into a nonlinear functional relationship making it simple to incorporate into the model.

The inclusion of nonlinearities tends to make systems intuitively unpredictable. This is illustrated by the unfamiliar modes of behavior that result when system dynamics models operate in extreme value regions for critical variables. This results in what system dynamicists call "counterintuitive behavior." This phenomenon is what system dynamicists feel is the greatest contribution of their methodology. Proponents of system dynamics models believe that complex systems are structured in such a manner as to be beyond the understanding of the human mind. In effect, the mind is incapable of correctly comprehending how these systems behave. Therefore, complex systems, which in the system dynamics world are higher-order nonlinear systems, behave in counterintuitive ways. So it is that system dynamicists feel that computer analysis, at least theoretically, can surpass the analyzing power of the human brain by carrying us through the complex logical sequences that are beyond our human perceptions.

It should be recognized that a counterintuitive result is a temporary result. This is due to the fact that no scientist will accept the result of a model that is so contrary to human expectation and understanding. Therefore when a counterintuitive result is encountered it is analyzed in detail with two possible outcomes: it is determined to be an error in the model itself or there develops a new understanding of the relationship of the variables involved. In either case the result ceases to be counterintuitive (Hughes, 1980).

In the modeling of systems, two categories are used: open and feedback. An open system has outputs that respond to inputs but its outputs are isolated from and have no influence on the inputs. In such a system, past action has no control over future action. Such a system cannot be aware of its own performance. A feedback system, on the other hand, is influenced by its past behavior. Such a system is composed of closed loops which result in bringing the consequences of past actions of the system back to bear on future actions.

System dynamics models fall in the category of feedback systems. Specifically, they involve eight components all arranged in hierarchical order. At the broadest point is the closed boundary. It is within this boundary that behavior is created independent of outside inputs. The closed system is made up of feedback loops. Within the feedback loops are two types of variables: levels and rates. Within the rate structure are goals, the apparent condition against which the goal is compared, the discrepancy between the goal and the apparent condition, and the action resulting from the discrepancy.

In examining a closed system we are interested in the interactions within the system that produce growth, fluctuations, and change. Formulating a model of a system should start from the question "Where is the boundary, that encompasses the smallest number of components, within which the dynamic behavior under study is generated?" (Forrester, 1968, p. 4-2). So, in concept a feedback system is a closed system. Its dynamic behavior is a result of the actions of its internal structure. All interactions which are imperative for the behavior being studied must be included inside the system boundary.

Feedback Loops

The system boundary is made up of feedback loops. There are two types of feedback loops. The negative feedback loop seeks a goal and responds as a consequence of failing to achieve the goal. The positive feedback loop generates growth processes wherein action builds a result that generates further action. A very broad system may imply a feedback system having many components. However, each of these components can itself be a feedback system. Therefore, there may be a hierarchy of feedback structures where the broadest of these determines the scope of the relevant system.

Jay Forrester describes the basic structure of a feedback loop as it appears in Figure 2-1. The loop is a closed path which connects a decision that controls action, the level of the system, and information about the level of the system, the latter which returns to the decision-making point.

The basis for the current decision is the information that is available at the time. The decision controls the action stream. The action in turn alters the level of the system. The level (true level) of the system is the generator of information about the system, but the information itself may be late or erroneous. The information is the apparent level of the system which may differ from the true level. It is the apparent level (information), not the true level that is the basis for the decision process. The illustrated loop structure is the simplest form of feedback system. This loop can be increased in size by additional delays and distortions appearing sequentially in the loop. Feedback loops may also be interconnected. It is the interaction of several feedback loops that generate dynamic behavior.

Levels and Rates

Within the feedback loops are levels and rates. These are simply two classifications of the variables in the system. All variables are included in one of these two categories. Each loop contains both

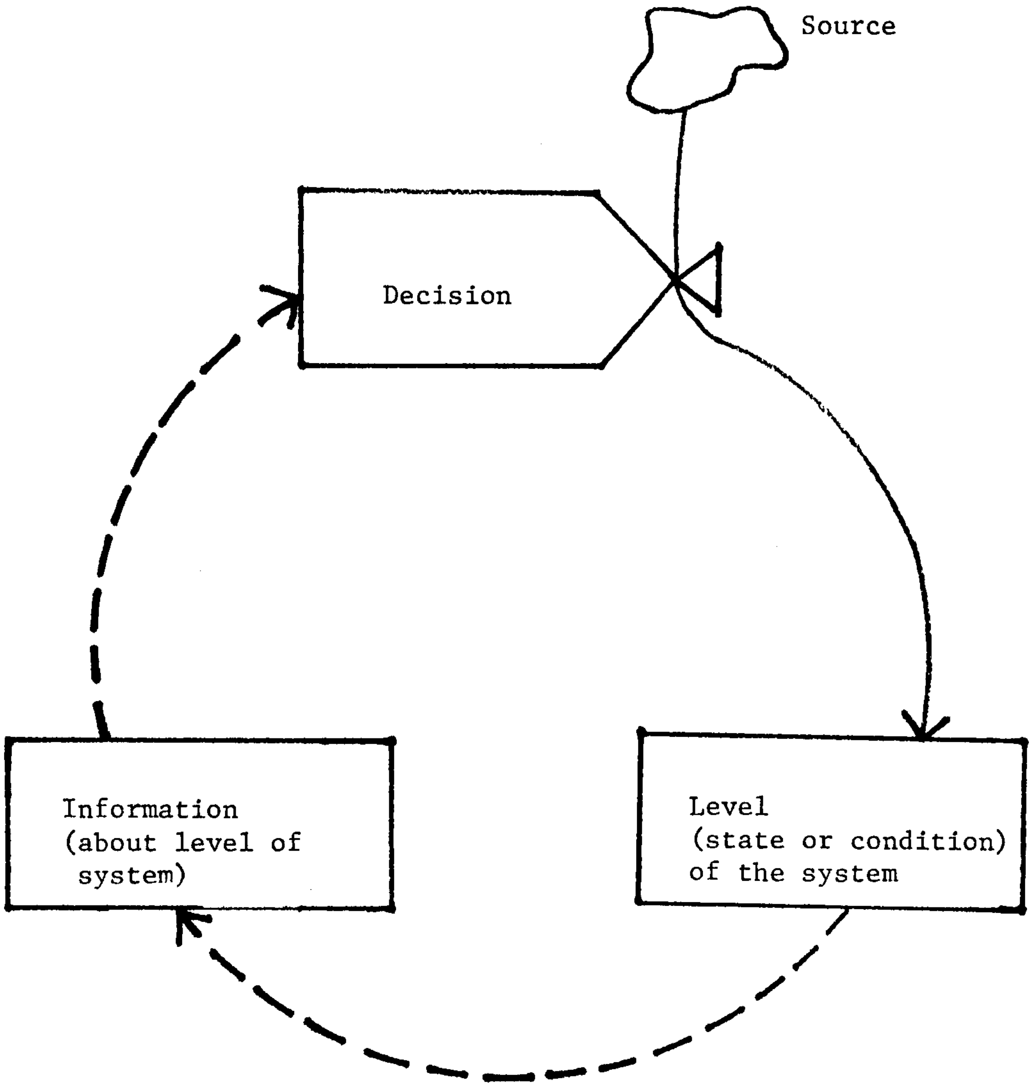

Figure 2-1. Feedback loop.

Source: Principles of Systems (p. 1-8) by Jay W. Forrester, 1968. Cambridge, Massachusetts: Wright-Allen Press. Copyright 1968 by Jay W. Forrester.

categories of variables. Level variables describe the state of the system at any point in time. Rate variables are instantaneous rates of flow which change the systems levels. Level variables accumulate the results of action within the system. Computing a new value of a level variable involves the previous value of that level variable itself, the rates (actions) that cause the level to change, and the length of time interval since the last computation of the level. The computation of the new value of a level does not involve the value of any other level variables. The level variables accumulate the flows described by the rate variables. The level equation represents a reservoir to accumulate the rates of flow that increase and decrease the content of the reservoir. The new value of a level is calculated, by adding or subtracting from the previous value, the change that has occurred during the intervening time interval.

The rate values tell how fast the levels are changing. They determine the slope of the level variables. The rate variables are defined by the rate equations. These are policy statements that describe action in the system. In effect rate equations state the action output of a decision point in terms of the information inputs to that decision. Computing the value of a rate variable is done using only the values of level variables and constants. The rate variable does not depend on its own past value, nor on the time interval between computations, nor on other rate variables.

Forrester (1968) lists several principles of levels and rates. Some of these are:

1. Levels are changed only by the rates. A level variable is computed by the change, due to rate variables, that alters the previous value of the level. The earlier value of the level is carried forward from the previous period. It is altered by rates that flow over the intervening time interval. The present value of a level variable can be computed without the present or previous values of any other level variables.
2. Levels and rates are not distinguished by units of measure. The units of measure of a variable do not distinguish between a level and a rate. The identification must recognize the difference between a variable created by integration and one that is a policy statement in the system.
3. Rates are not instantaneously measurable. No rate of flow can be measured except an average over a period of time. No rate can, in principle, control another rate without an intervening level variable.
4. Rates depend only on levels and constants. The value of a rate variable depends only on constants and on present values of level variables. No rate variable depends directly on any other rate variable. The rate equations (policy statements) of a system are of simple algebraic form; they do not involve time or the solution interval; they are not dependent on their own past values.
5. Level variables and rate variables must alternate. Any path through the structure of a system encounters alternating level and rate variables.
6. Levels completely describe the system condition. Only the values of the level variables are needed to fully describe the condition of a system. Rate variables are not needed because they can be computed from the levels. (pp. 4-7–4-12).

Rates can also be divided into a substructure called a rate equation. A rate equation is a policy statement. It tells how an action stream is generated. The rate equation is instantaneous in its behavior. It is a pure algebraic expression that states the present flow rate in terms of the present information. Since it is algebraic the rate equation is free of lags and time-dependent distortion. All time-dependent changes in the character of a flow are created by the level equations.

Rate Equations

There are four major characteristics of the rate-equation structure of a system dynamics model (Council on Environmental Quality and the Department of State, 1980).

1. Rate equations are formulated on the basis of observation of the underlying real-life decision processes. All information inputs to a rate equation are information sources actually available to the decision-maker and employed in decision-making. Rate equations should not be based on a theory of equilibrium or optimal economic behavior.
2. In a well-formulated model, parameters will each have clear and independent real-life meaning. A typical parameter might represent the average length of time orders for capital equipment are planned and negotiated internally before an actual order is placed with suppliers. Parameters should have operational significance to actors in the real system, not just abstract statistical meaning. Parameters should never be inserted just to correct units of measure or to increase equation fit with data.
3. Proper rate-equation formulations should incorporate all influences on the corresponding real-life action, including intangible or nonmeasured variables. Nonmeasured variables or variables for which little data exist should be formulated and incorporated into the model in as reasonable a way as possible, given data limitations. Simulation experiments should then be performed at a later stage to assess the sensitivity of model behavior and policy outcomes to the exact measurement and specification of intangible or nonmeasured influences. Such simulation experiments can guide further data-collection and parameter-specification efforts.
4. Rate-equation formulations should be robust and not break down at extreme conditions or outside the range of observed system behavior. Such robustness of rate equations is important because it can seldom be presumed a priori that future behavior or behavior resulting from application of a new policy will fall only within the range of past behavior. (p. 609)

There are four components of a rate equation. They are (1) a goal, (2) an observed condition of the system, (3) a way to express the discrepancy between goal and observed condition, and (4) a statement of how action is to be based on discrepancy. These components are illustrated by Forrester (1968) in the manner found in Figure 2-2. The rate equation can also be stated as:

$$OR = 1/AT\ (DI - I)\ ,$$

where OR = Order rate (units/week); AT = Adjustment time (weeks); DI = Desired Inventory (units); and I = Inventory (units). In this example equation, the goal is the desired inventory DI. The order rate acts to move inventory toward the goal. The observed condition of the system is the inventory I. The discrepancy between the desired and apparent conditions of the system are here taken as the simple difference (DI - I). The action in the above rate equation is stated to be 1/AT of the discrepancy. In general, a policy or rate equation recognizes a local goal toward which that decision point strives, compares the goal with the apparent system condition to detect a discrepancy, and uses the discrepancy to guide action.

In the positive feedback loop, the goal takes on a somewhat different meaning than in the negative feedback loop. In the negative loop, the goal is the system condition that is being sought. In the negative loop, the rate equation created a rate of flow that tries to move the condition of the system toward the goal. In the positive feedback loop, "goal" takes on the reverse meaning. In the positive feedback loop the goal is that value from which the system is departing in its ever-increasing growth.

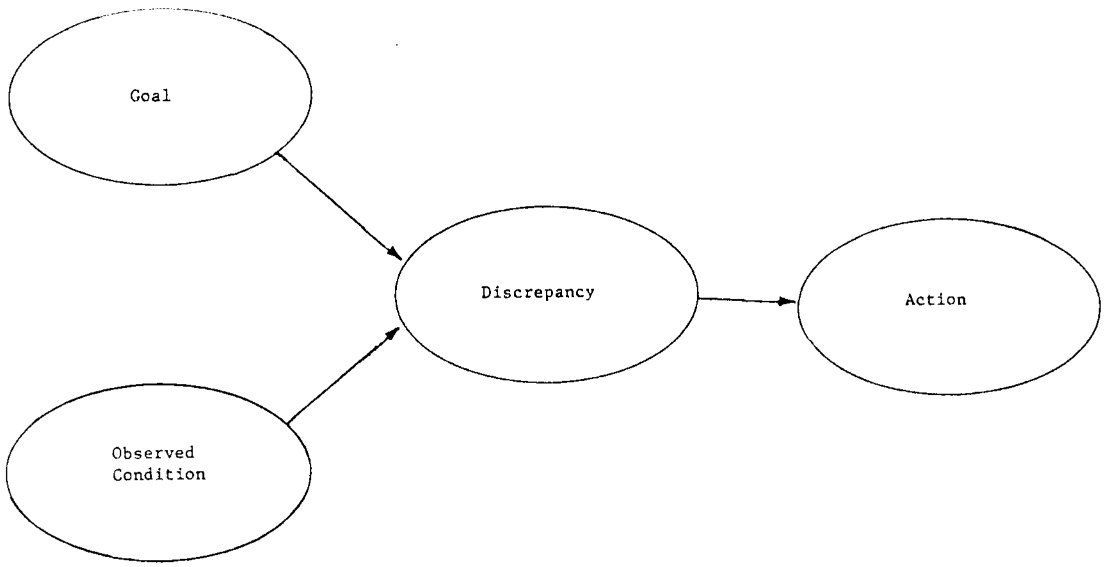

Figure 2-2. Components of a rate equation.

Source: Principles of Systems (p. 4-15) by Jay W. Forrester, 1968, Cambridge, Massachusetts: Wright-Allen Press. Copyright 1968 by Jay W. Forrester.

Structure of World2 and World3

World2 and World3 are very similar. World3 is a continuation of, and therefore a refinement and improvement over World2. A comparison of the flow diagrams of the two models illustrates the much higher degree of complexity and thoroughness involved in World3 over World2. For this reason World3 will be discussed rather than World2. (Specific information on World2 can be found in World Dynamics by Jay Forrester (1971).)

In determining the sectors to be included in World3, the original modeling team developed a verbal description of the system within which the world's problematique was observed. Their description is as follows (Meadows et al., 1974):

> The complex system represented in World3 has historically exhibited increasing growth rates of population, industrial output, food production, and resource use. All this productive and reproductive activity is based on complex ecosystems that provide the maintenance functions necessary for human society. These ecosystems are governed by immutable physical laws and are vulnerable to degradation from misuse. The human social system is composed of political and economic institutions that respond to perceived shortages, primarily through the development of new technologies. (p. 7)

From this verbal description came the identification of five sectors of examination. They are (1) population, (2) capital, (3) agriculture, (4) nonrenewable resources, and (5) pollution. These will be examined in further detail later in this section.

Time Horizon of World3

Next the modelers determined a time horizon for the model. The time horizon chosen for any model usually corresponds either to the time necessary for the system to manifest a behavior mode of interest or to the time period required for the system to respond fully to some new set of policies. The dynamics of human life and capital growth and their interaction with the environmental carrying capacity could easily extend over 100 years. The modeling team decided on a time horizon of two centuries for World3, beginning in 1900. The starting date was chosen to provide a rough test of the utility of the model. Historical data from 1900 to 1970 could be compared to the model's behavior. The analysis was not carried beyond 2100 due to the decreasing validity of assumptions as they are projected further into the future. It was also determined that information about events that would happen beyond 2100 would have little impact on policy-making in 1970.

The choice of a 200 year time horizon limited the dynamic processes that could be examined in the model. Six dynamic phenomena were identified as occurring over the relevant time period and conceivably influencing the behavior of the system. These include: (1) demographic transition, (2) soil erosion, (3) displacement of labor with capital, (4) passage of pollutants through food chains, (5) health care advances, and (6) resource substitution. All of these are included in the five aforementioned sectors of the model. Events that take place over a very long period of time, compared to the model's time horizon (i.e., ice ages and genetic evolution), or a very short period of time (i.e., minor business cycles and seasonal weather changes) were treated in one of three ways: they were excluded from the model entirely, represented by a constant factor, or subsumed in the models coefficients. A great degree of detail was not sought by the modeling team. They wanted only the basic elements that are both necessary and sufficient to represent the interaction of the human population with the environmental carrying capacity.

Interactions of Primary Model Sectors of World3

Figure 2-3 shows the interactions of the five sectors of World3 as described by the modeling team. Each of these sectors will be examined in closer detail. Population and capital are the two sectors most responsible for material growth. People incorporate economic and environmental factors in their lives which influence human birth and death rates and therefore population size. Capital is the means by which industrial service and agricultural outputs are produced.

As these two sectors grow, they stimulate the development of new technologies which, in turn, allow for the more efficient use of the earth's resources. However, this increasing population and number of factories require more resources. For this simple reason the last three sectors are represented in the model. The sectors are all separate determinants of the environmental carrying capacity. The agricultural sector includes all land and other factors affecting the impacts of capital inputs on food production. The nonrenewable resource sector represents the fuel and mineral inputs required to make use of the capital supply for producing goods and services. The last sector, pollution, includes all persistent materials produced by industry and agriculture that may reduce human life expectancy, agricultural productivity or the normal ability of ecosystems to absorb harmful substances.

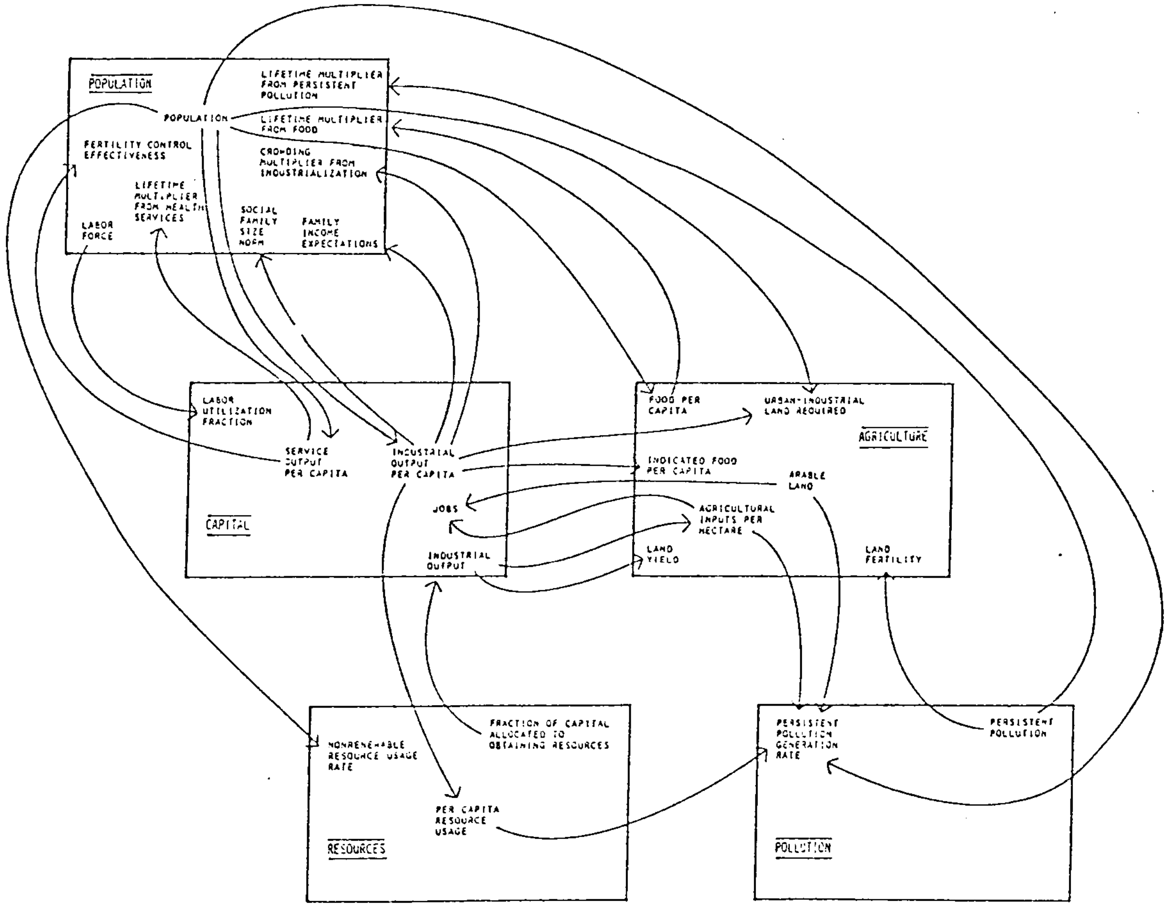

Figure 2-3. Interactions among the five basic sectors of World3.

Source: Dynamics of Growth in a Finite World (p. 11) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

Many other sectors could have been included in the model as separate sectors. However, the modeling team decided to deal with these in various ways. For example, renewable resources such as fresh water, forest products, and fish could have been included in addition to food. Based on the expert knowledge of its various members, the team decided that these resources were so dynamically similar to food that their inclusion in the model would not produce any different behavior modes. Energy also could have been a separate sector. However, the modeling team felt that the long-term behavior of fossil energy reserves is dynamically similar to that of other nonrenewable resources. They decided, therefore, to subsume traditional energy resources into the nonrenewable resource sector. The vast number of human sociopolitical institutions could have been a separate sector. These factors define our goals and values and therefore greatly affect the growth of population and capital and the use and allocation of resources. Instead, the modeling team chose to represent these factors throughout the existing five sectors. On the whole, the team chose only those factors representing the gradual effects of the social system as it changes human values in response to new economic or environmental situations.

Level of Aggregation of World3

World3 is a highly aggregated model. It is by far the most aggregated of the three models examined here. The population is partially disaggregated by age, but not by nationality or income. Capital is divided into four categories: industrial, service, agricultural, and that used for obtaining resources. Land is separated into three categories: potentially arable, arable, and urban-industrial. Neither the pollution sector nor the resource sector is disaggregated. Each of these sectors contains only one state variable that characterizes a typical persistent pollutant and nonrenewable resource, respectively.

The model is not divided into economic or geographic territories. The modelers felt that this level of aggregation was justified by three factors. First, they felt that the physical system connecting population with the carrying capacity of the environment was structurally the same in any geographic region. Secondly, they also expected the physical causes of instability and the policies that lead to material stability to be the same from region to region. Thirdly, the modelers believed that the systems that distribute and assimilate persistent pollutants and govern the technology and amount of resource use are basically global.

Flow Structure of World3

Plate 1 (in pocket) shows the full DYNAMO flow structure of World3. World3 was run on a DYNAMO compiler which is a computer program which accepts the equations for a model of a dynamic feedback system and produces the requested simulation results as numerical tables and graphical plots. Appendix A lists the variables and their abbreviations used in the flow diagrams for World3. (DYNAMO, which stands for DYNAmic MOdels, was designed by the Industrial Dynamics group at the Sloan School of Management at MIT.)

The DYNAMO compiler accepts a model written in the form of level, rate, and associated equations. Forrester (1968) identified the functions of the model compiler to be:

1. It checks the equations for any logical errors and prints defects. Many errors that can occur in a set of equations can be located because they do not satisfy the logical concepts of a feedback model.
2. It reorganizes the model in accordance with the structural concepts of a dynamic system, grouping level and rate equations, and arranging the required sequences of those auxiliary equations which depend on one another.
3. It programs the model. That is, the equations with their algebraic notation are converted to detailed computer operating instructions.
4. It executes the step-by-step computation, based on the control instructions that give solution interval and run lengths, and produces the simulated results of the system represented by the model.
5. It prepares and prints the requested output in tabular and graphical form. (pp. 8-1–8-2)

Population and Capital Sectors of World3

The population and capital sectors are two critical sectors in the World3 system. Both produce the potential for exponential physical growth in the model. In the population sector an increased number of human births increases the population, which leads to still more births. Similarly, an increased rate of capital investment adds to the industrial capital supply which in turn makes possible a greater industrial output. This increased output allows for more investment which raises the supply of capital still higher.

Both capital and population growths are exponential. So, annual increases in population or capital depend in part on the amount of existing population or capital. "Whenever the rate of growth of any quantity varies directly with the amount of that quantity, a positive feedback loop is present, and growth, if it occurs at all, will be exponential" (Meadows et al., 1974). The DYNAMO flow diagrams for these two sections can be seen in Figures 2-4 and 2-5. The symbols used in the diagrams are defined in Appendix B.

Agriculture, Resource, and Pollution Sectors of World3

In addition to these positive feedback loops, World3 contains several negative feedback loops which may balance or even overbalance the positive forces for exponential growth. Their relative effectiveness constantly changes as growth progresses, causing the balance between growth forces and stabilizing forces to continually shift. Variations in the set of inputs from the environment can produce negative, positive, or zero rates of growth of population and capital at different times. World3 contains no constant exponential growth rate for either population or capital. However, when positive forces are dominant the model will generate exponential growth at a rate that may vary over time.

The negative feedback loops are contained primarily in the agriculture, resource, and pollution sectors of the model. They are in the form of assumptions about the physical limits of the global system. These limits are dynamic and can be raised or lowered. World3 incorporates the following assumptions about these limits (Meadows et al., 1974):

1. The amount of potentially arable land that can be developed into actually cultivated land through the investment of capital is finite. As the stock of potentially arable land is diminished, the marginal cost of land development, measured in terms of capital and energy, increases.

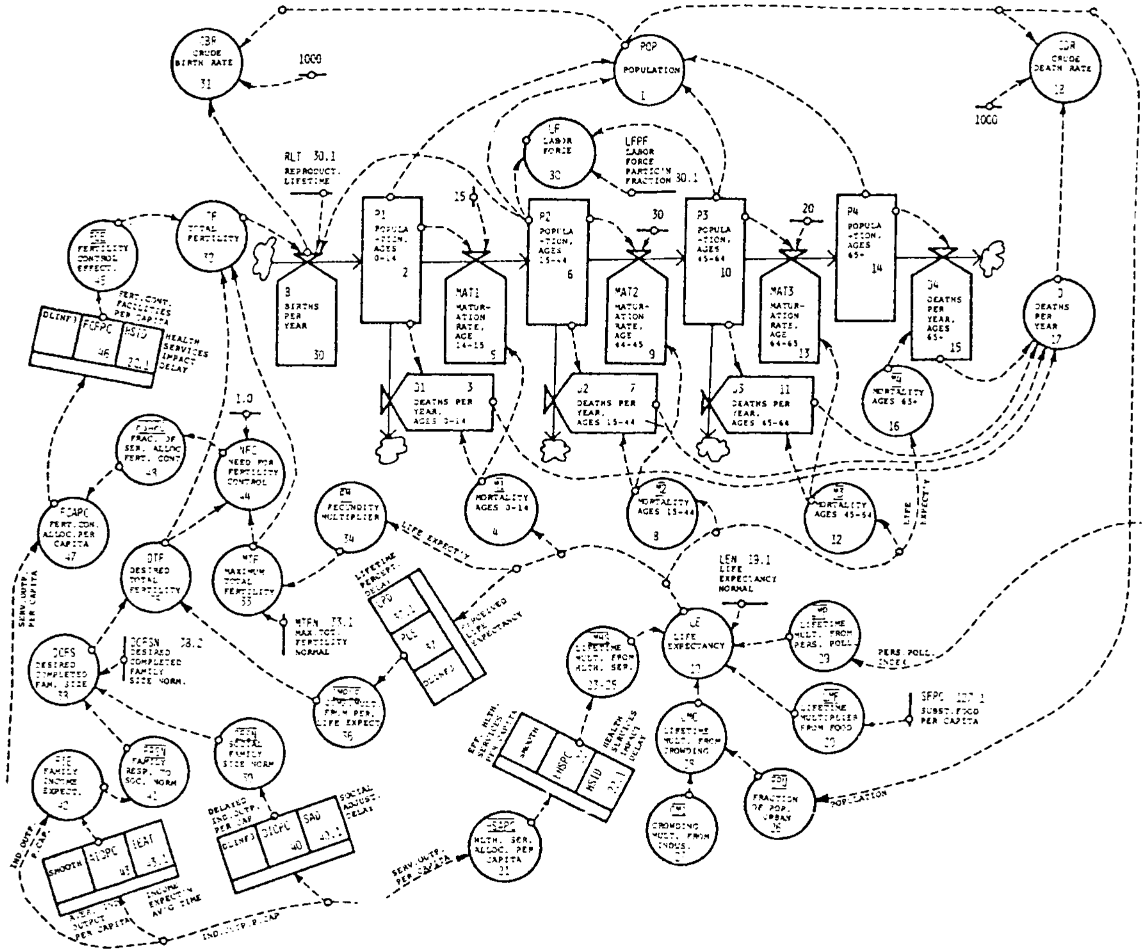

Figure 2-4. DYNAMO flow diagram of one age level of the population sector of World3.

Source: <u>Dynamics of Growth in a Finite World</u> (p. 56) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

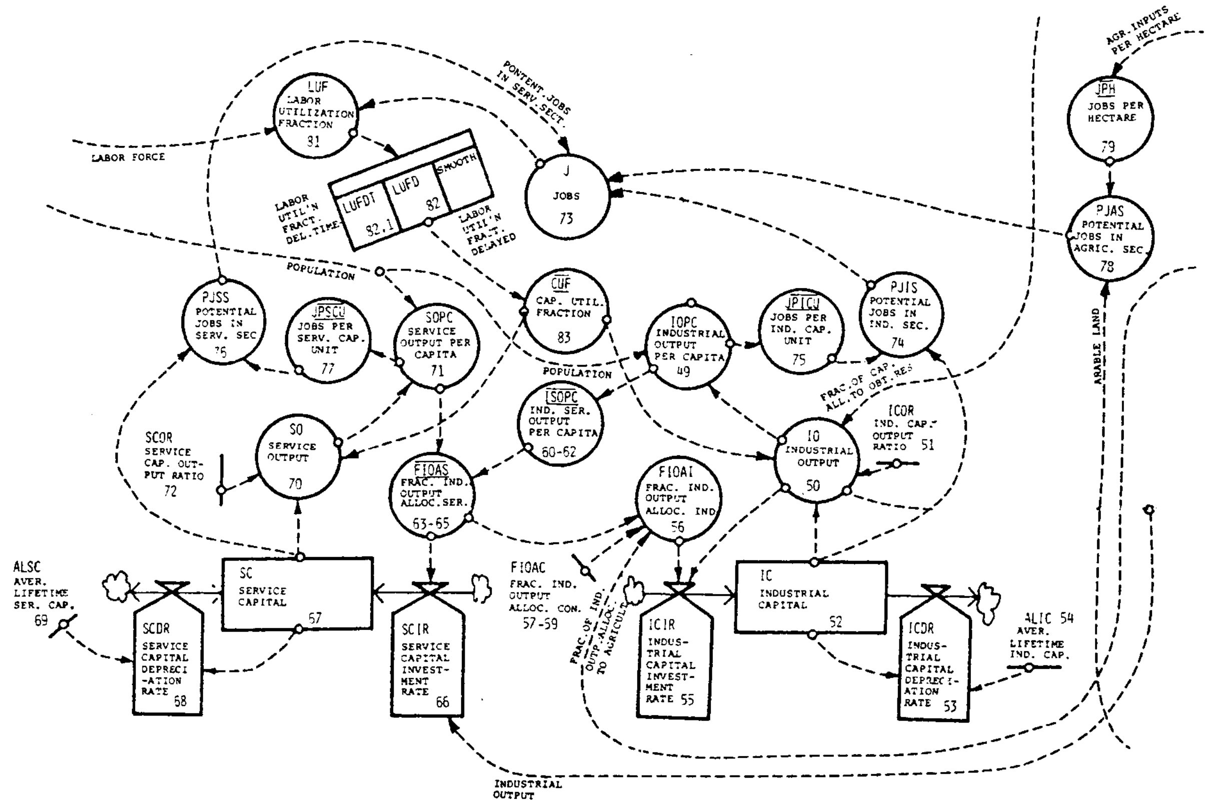

Figure 2-5. DYNAMO flow diagram of the capital sector of World3.

Source: Dynamics of Growth in a Finite World (p. 215) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

2. There is a limit to the amount of food that can be produced from each hectare of arable land each year. This limit can be approached by investment in agricultural inputs such as fertilizers, pesticides, and tractors. Eventually, however, there are diminishing returns to these inputs. The land yield limit can be decreased by very high levels of pollution of overintensive cultivation, and it can be restored to its original value by investment in land maintenance.
3. The stock of nonrenewable resources in the earth is finite. The absolute limit of available resources is the entire mineral content of the earth's crust. However, long before that limit is reached, the marginal cost--in capital and energy--of extracting and processing each unit of resource will rise to prohibitive levels.
4. There is a limit to the rate at which environmental pollutants can be rendered harmless by natural assimilation processes. Pollution levels can be kept below that limit by reducing the toxicity or quantity of industrial and agricultural emissions. However, pollution control requires capital investment, which is subject to diminishing returns. Moreover, the rate of natural pollution absorption can be lowered by the pollutants themselves if they reach levels that interfere with the environment's assimilation mechanisms. (pp. 15-16)

The flow diagrams for these three sectors are given in Figures 2-6, 2-7, and 2-8. In World3, these physical limits provide negative feedbacks to population and capital growth. They only become strong enough to balance the positive feedback forces of physical growth when that growth brings capital or population close to assumed absolute limits. Negative feedback is also provided by various social processes, such as shifts in relative prices, advances in technology, and changes in social values. All of these can act to adjust the rate of interaction between the growing population and the ultimate carrying capacity of the environment.

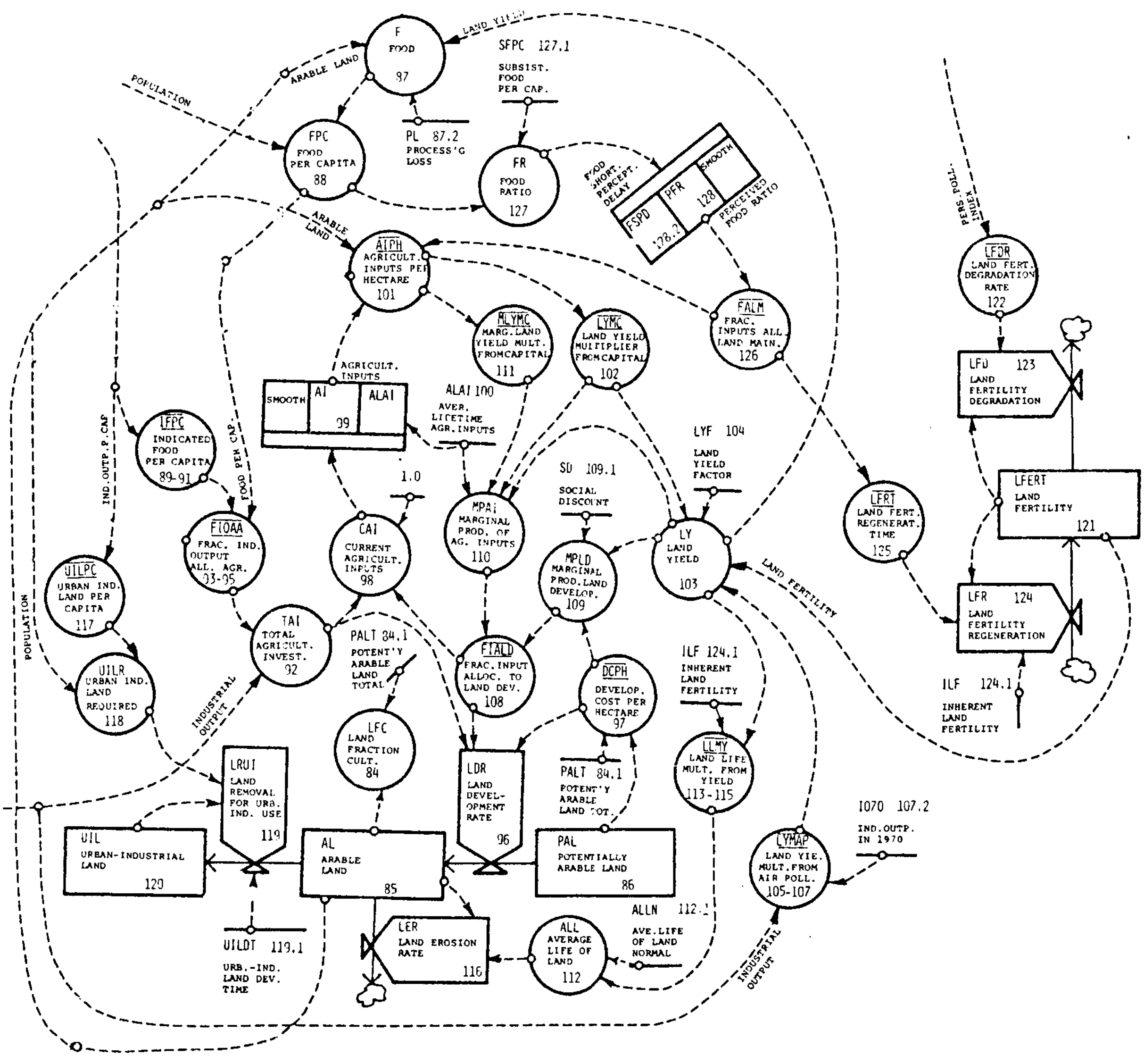

Figure 2-6. DYNAMO flow diagram of the Agriculture Sector of World3.

Source: <u>Dynamics of Growth in a Finite World</u> (p. 277 by Dennis L. Meadiws et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

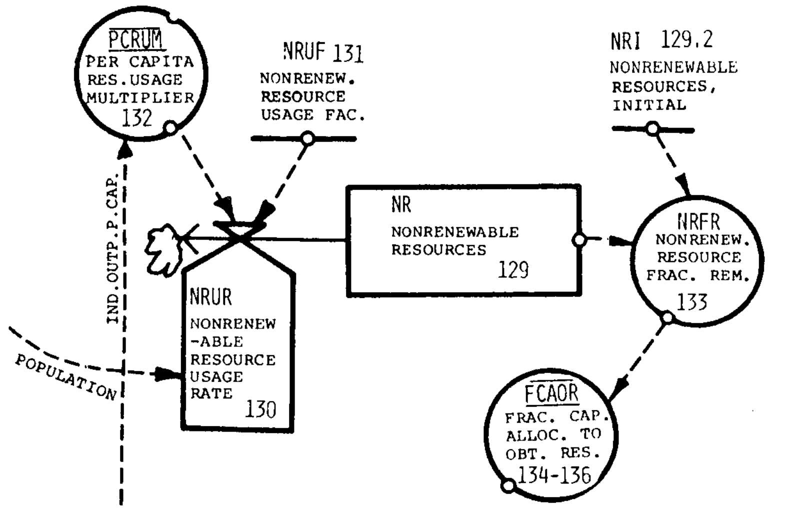

Figure 2-7. DYNAMO flow diagram of the nonrenewable resource sector of World3.

Source: Dynamics of Growth in a Finite World (p. 384) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

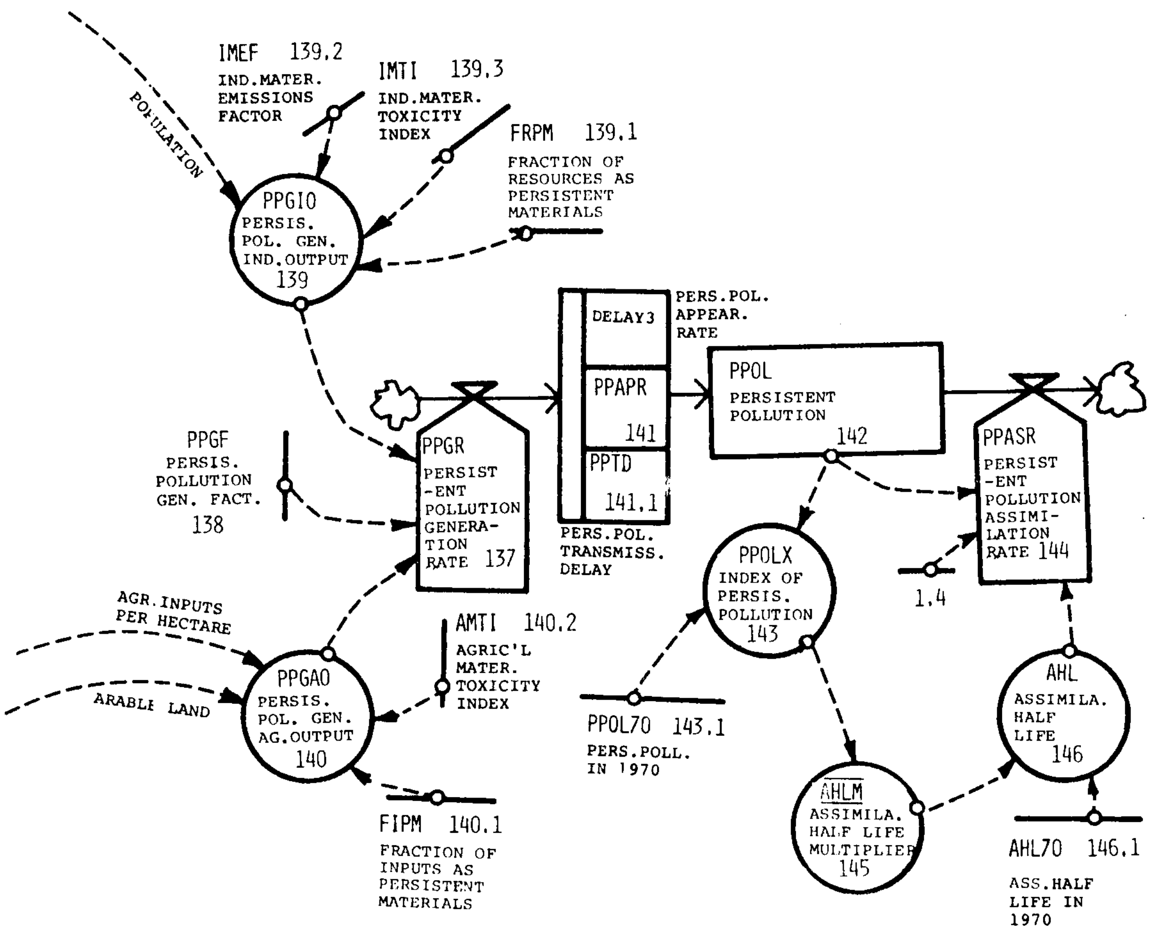

Figure 2-8. DYNAMO flow diagram of the pollution sector of World3.

Source: Dynamics of Growth in a Finite World (p. 427) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright--Allen Press.

Social Feedback Mechanisms in World3

World3 has interspersed various social factors throughout all five of the major model sectors. They are all contained in three categories of social processes: (1) economic price, (2) technological advance, and (3) human values.

Economic price is a function of two socially determined variables: the marginal value society places on a specific good or service, and the apparent marginal cost of supplying that good or service. Economists believe that the price system performs a long-term stabilizing function in economic systems by signaling resource scarcity. A price increase may trigger any number of social responses.

Several of the relationships between the supply of some material and the response of the economic system to that scarcity are included in World3. Within the model the relationship has been represented in a shortened fashion from

decrease in supply → rise in price → social response

to

decrease in supply → social response.

Therefore, the price mechanism is included but is not explicitly represented in the model. The modeling team felt that such a representation of the price mechanism was adequate due to the long-term insignificance of its behavior in a 200-year time horizon. The modelers did realize however, that this use of the price mechanism tends to make World3 overestimate the stability of the real-world system.

The second social process included in World3 is that of technological advance. Nearly every causal relationship in World3 could conceivably be changed by some sort of new technology. Therefore the modeling team built technological change directly into each model relationship as they formulated it. This was accomplished by assigning all possible technologies to three categories: already feasible and institutionalized, feasible but not institutionalized, and not yet feasible.

Throughout history, some causal relationships have been influenced by technology and continue to be so today. These relationships are characterized by the consensus of the social majority that change is desirable and by the existence of the resources and institutions necessary to enact the changes. Some examples include medical technology to improve health, industrial technology to raise production efficiency, agricultural technology to increase land yields, birth-control technology to control family size, and mining technology to discover and exploit lower-grade nonrenewable resources. These relationships are built into World3 with the assumption that they will continue as long as economic support for them continues.

Other types of technologies have not been widely accepted. These technologies include pollution control, resource recycling, the capture of solar energy, supersonic transports, fast-breeder reactors, and increased durability of manufactured goods. It is not certain that all the regions of the world would be willing to implement these technologies. Therefore, the modeling team incorporated many of these relationships as optional functions that anyone utilizing World3 could activate at any specified time in the model run.

The last social process included in World3 is that of values. Whereas values are not directly represented in the model, they are included in the form of assumptions about human goals as they influence and are influenced by the processes of physical growth. In examining the various types of human values, the modelers decided to include only those that were universally held. These values include those necessary for survival--such as food, water, and shelter. Some higher-level values are also included such as longevity, children, material goods, and social services such as education. These are all included either explicitly or implicitly in the model.

All values in World3 are incorporated into the feedback loops. However, the modeling team limited the patterns of change to those historically observed over the past 100 years. The process of industrialization has been the dominant process of change over this time period. Therefore, the values that both shape and respond to the development of the model system follow the historical patterns observed during industrialization. This can be seen in the model's loop structure as any increase in industrialization (which is measured by the level of industrial output per capita), causes aggregate social demand shifts in emphasis from food to material goods and finally to services. Unprecedented value changes are represented in the model structure by a set of switches which the operator can use to express his own hypotheses about future social development.

Results of World3

All conclusions gleaned from any model are subject to the basic assumptions made in the model run. The dominant behavior mode of World3 is caused by three basic assumptions about the population-capital system (Meadows et al., 1974):

> 1. The prevailing social value system strongly favors the growth of population and capital. Therefore, these quantities tend to grow unless severely pressed by physical limitations. Their growth is exponential because of the inherent positive feedback nature of industrial production and human reproduction.
> 2. Feedback signals about the negative consequences of growth are generated by the environmental systems that support population and capital. These signals take the form of pressures against growth, such as diminishing returns to investment in inputs, the buildup of harmful pollutants, increased development costs for new land, increased resource costs, and less food per capita. The negative feedback signals become stronger as population and capital grow toward environmental limits.
> 3. Delays in the negative feedback signals arise for two reasons. First, some delays, such as those inherent in population aging, pollution transfers, and land fertility regeneration, are inescapable consequences of physical or biological laws. Second, some delays are caused by the time intervals necessary for society to perceive new environmental situations and to adjust its values, institutions, and technologies in response. (pp. 561-562)

These three characteristics--rapid growth, environmental limits, and feedback delays--make for an unstable world system. Because the rapid growth persists while the feedback signals that oppose it are delayed, the physical system can temporarily expand well beyond its sustainable limits. During this period of overshoot, the short-term efforts required to maintain the excess population and capital are likely to erode or deplete the resource base. The environmental carrying capacity may also be diminished to the point where it can only support a much smaller population and lower material standard of living than would have been possible before the overshoot. The result is an uncontrollable decline to lower levels of population and capital.

Once the system characteristics that lead to instability are understood, it becomes relatively easy to evaluate alternate policies for increasing stability and bringing about a sustainable equilibrium. The modelers defined four such alternative policies (Meadows et al., 1974):

1. Short-term technologies designed to mask the initial signals of impending limits and to promote further growth will not be effective in the long term. Rather, they will disguise the need for social value change, lengthen the system's response delays, and increase the probability, the speed, and the magnitude of the eventual overshoot and collapse.
2. Policies that combat the erosion of the earth's resource base will certainly reduce the severity of decline after an overshoot. However, so long as growth is still emphasized and feedback delays persist, resource conservation will not in itself prevent overshoot. Furthermore, the overstressed system may not be able to afford the costs of conservation during a period of overshoot.
3. Social value changes that reduce the forces causing growth, institutional innovations that raise the rate of technological or social adaptation, and long-term forecasting methods that shorten feedback delays may be very effective in reducing system instability.
4. A judicious combination of policies designed to prevent the erosion of resources, foresee the effects of approaching limits, and bring a deliberate end to material and demographic growth can circumvent the overshoot mode altogether and lead to a sustainable equilibrium. (p. 562)

Without an examination of the output of World3, policy is based on a much different view of the world held dominant by the world's policy-makers. This view holds "that physical growth can and should continue; that technology and the price system can eliminate scarcities with little delay; that the resource base can be expanded but never reduced; that the solution of short-term problems will yield desirable long-term results; and that population and capital, if they must ever stabilize, will do so automatically and at an optimal level" (Meadows et al., 1974, pp. 561-563).

The results of World3 and this contemporary dominant view of the world are widely opposed. World3 suggests that changes in social institutions and values are necessary to avoid collapse due to the basic instabilities of the world system. The contemporary view of the world, however, holds that the requisite stabilizing mechanisms already exist and no future events will necessitate more than minor adjustments in current policy.

CHAPTER 3

THE WORLD INTEGRATED MODEL

Methodology of Hierarchical Systems Models

Mesarovic and Pestel's World Integrated Model is based on hierarchical systems theory. Unlike the system dynamics theory of World2 and World3, hierarchical systems theory separates the modelers' world view and the mathematical structure used to build the model. In hierarchical systems theory, the mathematical and computer techniques are used (eclectically) to represent the modeler's view of the world. In such a system, the modeler's view is of as much interest as the mathematical methods used in the structure of the model.

The World View

The modelers' view of the world in the World Integrated Model (WIM) is that of a world stratified into multiple planes, each of which operates with a certain degree of autonomy. Mesarovic and Pestel refer to these planes as "strata" and have them hierarchically arranged as can be seen in Figure 3-1. At the top of the order is the individual stratum followed in descending order by the group, the demographic-economic, the technological, and the environmental (ecological and geophysical) strata.

Mesarovic and Pestel provide an explanation for the use of such a hierarchical systems approach to viewing the world. They developed this approach in response to the inability of the existing models to

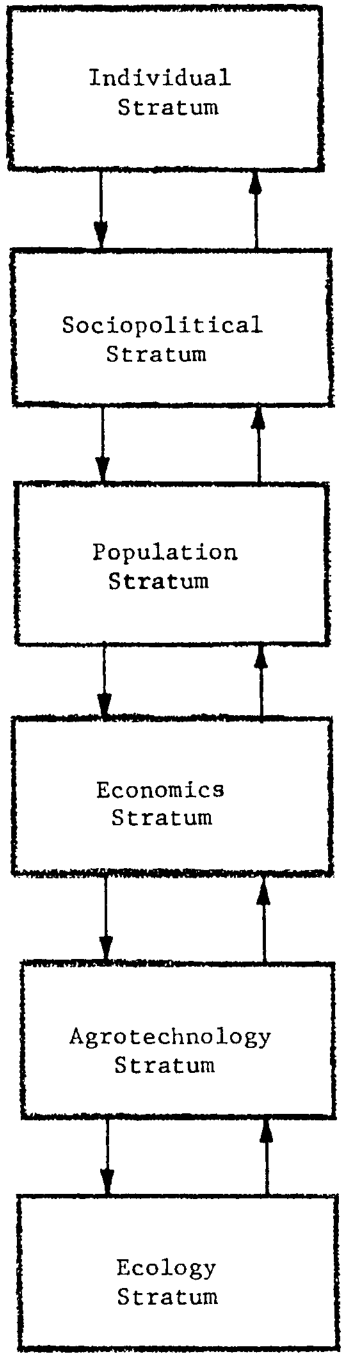

Figure 3-1. The five strata of the World Integrated Model.

Source: Global 2000 Report to the President (p. 616) by Council on Environmental Quality and the Department of State, 1980, Washington, D.C.: U.S. Government Printing Office.

represent the world in a manner which they considered to be appropriate and correct. The development of this approach is explained below and is represented in Figure 3-2. In examining the approaches to answering the world's food supply problems that existed at that time, Mesarovic and Pestel found two popular approaches: the accountant's method and the greenhouse approach. The accountant's method holds that all that is necessary to solve the world food supply problems is a 3 or 4 percent growth in economic output. The greenhouse approach holds that since it is possible to increase the yield substantially in a laboratory, we can feed, for example, thirty billion people.

Mesarovic and Pestel questioned the validity of these two approaches when being used separately. Together the two approaches form what Mesarovic and Pestel call a delayed greenhouse approach. Within this structure a realistic assessment can be made as to how much food could be produced in what time period in various regions. But then the question arises as to how the needs governed by population development in specific regions are related to such an increase in food production and nutrition.

Economics, agrotechnology, and population have to be considered as a system. Mesarovic and Pestel call this system the ultimate greenhouse approach. In such a system the needed food would eventually be produced. The resulting increase in food production, however, would require that all but a miniscule number of crops--which are needed to support man--be eliminated from the arable land anywhere in the world. It would also involve the use of chemicals on an unprecedented scale.

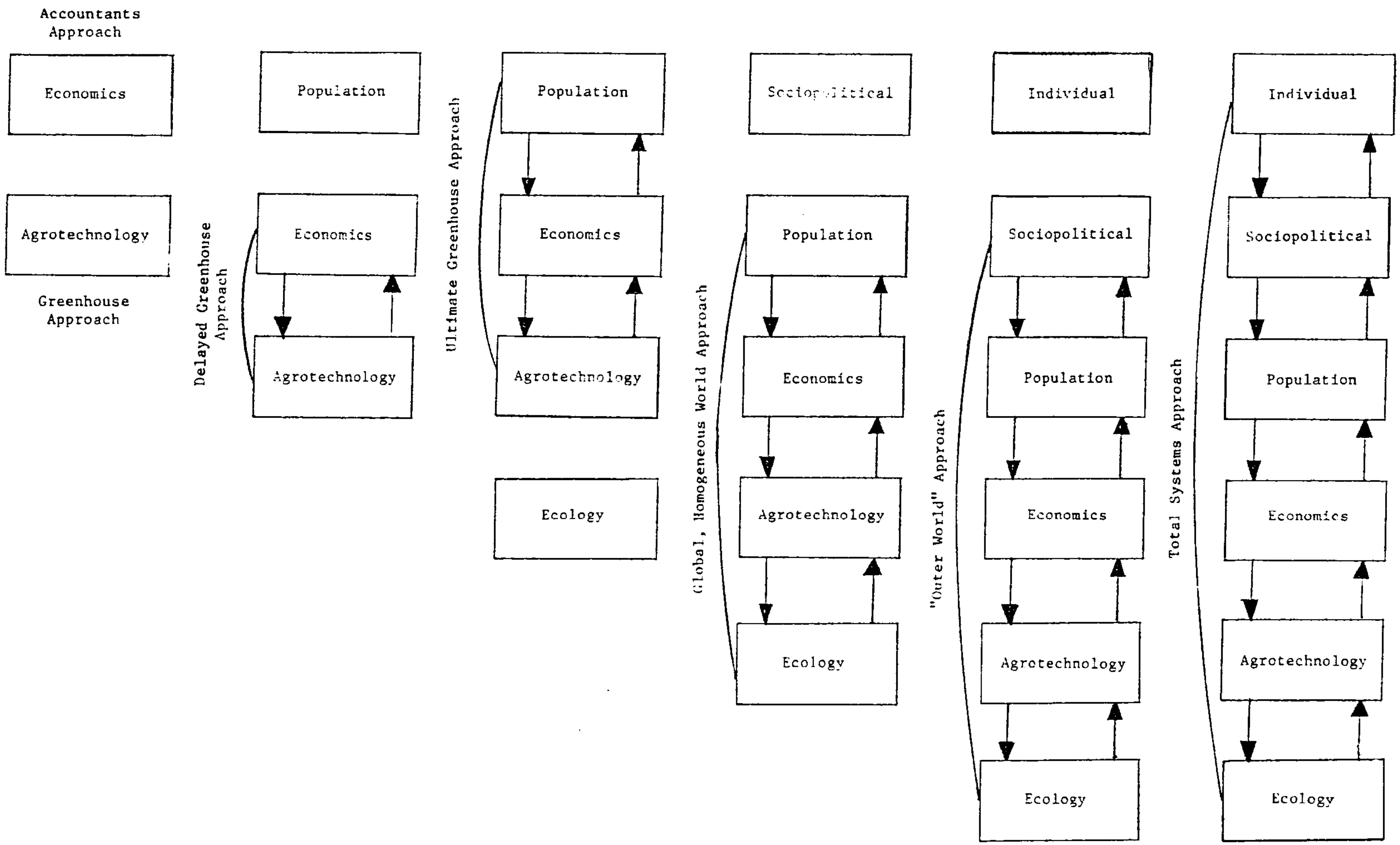

Figure 3-2. The development of the hierarchical systems approach.

Source: Mankind at the Turning Point (pp. 28-29) by Mihajlo Mesarovic and Eduard Pestel, 1974, New York: E. F. Dutton. Copyright 1974 by Mihajlo Mesarovic and Eduard Pestel.

This approach raises yet another question as to whether a system which is so drastically reduced in nature and in which a vast majority of species has been eliminated can survive over a period of time.

In order to solve the last question, Mesarovic and Pestel felt that economics, agrotechnology, population development, and ecology have to be considered as a system. This raises new questions. The world is not an uniform system. Eventually the place where additional food can be produced and the place where food is needed will not be the same. How will the sociopolitical arrangements of the world be affected by food as a potential weapon?

This leads to the need to view economics, agrotechnology, population development, ecology, and global sociopolitical arrangements as a system. The emergence and continued existence of such a global integrated system would require a change in attitudes and values which individuals hold with respect to society and world community as well as with respect to the sacrifices needed to protect future generations against major crises.

In order to include the individual, Mesarovic and Pestel developed their total systems approach to be hierarchical in nature. In such a system economics, agrotechnology, ecology, population development, sociopolitical arrangements and the individual's values and norms are all considered in order to provide a more realistic and practical consideration of the world food situation. Figure 3-2 illustrates the development of the various systems into the total systems approach.

In practice the strata are not equally represented in the model. The demographic-economic stratum and the environment stratum are represented in the most detail and take up the majority of the model's content. The modelers have made the system interactive by allowing the model user to estimate social group behavior which is fed into the group stratum.

Like Forrester, Mesarovic and Pestel view social systems as being too complex for the human mind to understand. However, Mesarovic and Pestel offer a different explanation than that of counterintuitive behavior for this failure to comprehend. Hierarchical systems theory holds that the inability of the human mind to understand social systems arises from the construction of these systems. In normal times the different hierarchical strata behave almost independently of one another. However, some conditions can cause the strata to become interactive. The modelers refer to these situations as crisis conditions. In a crisis situation, the various strata cannot adjust to the changes in their environment and so pull on one another. This results in every variable on any level becoming dependent on variables from other levels. Under such conditions the system adopts modes of behavior so different from those of normal experience that they surpass our human perception.

Experimenting with the hierarchical systems structure, Mesarovic and Pestel developed hypotheses as to what was necessary to bring the system back from crisis to normal conditions. They determined that what was needed was not to change the path of development by "outside" steering into the direction of further growth or nongrowth. They felt that what was needed instead was an internal restructuring of the system to restore the normal condition where the subsystems are in mutual harmony so that each of them, by solving its own problems, is contributing to the solution of the whole.

Another world view held by the hierarchical systems modelers is that of organic growth versus undifferentiated growth. Mesarovic and Pestel (1974) explain undifferentiated and organic growth using the following analogy of cell division.

> In the undifferentiated type, growth occurs through replication of cells by cell division: one cell divides into two, two into four, four into eight, and so on until, very rapidly, there are millions and billions of cells. . . . In undifferentiated growth all the new cells are replicas of the first; growth is in quantity only. The result is a purely exponential increase of the cells' numbers. Organic growth, in contrast, involves a process of differentiation, which means that various groups of cells begin to differ in structure and function. . . . During and after differentiation, the number of cells can still increase, and the organs grow in size; but while some organs grow, others might decline. . . . The equilibrium reached in organic growth is dynamic, not static. (p. 4)

Structure of the World Integrated Model

> Mathematically, the WIM is somewhat like a system dynamics model in which state variables are replaced by matrices of state variables, and the necessary equipment is added to describe interaction between the elements into which the single variables have been disaggregated. (For instance, one can think of the model as having been regionalized through first building a single regional model structure and then replicating it ten or twelve times, using parameter differences and perhaps computer subroutines to make the individual regional model conform to characteristics of the world's region.) Thereafter it was necessary to link the regions in a trade network." (Council on Environmental Quality and the Department of State, 1980, p. 617)

This same sort of disaggregation used to develop regions is used in other places in the model. For instance, the world's population is broken down into 87 separate age groups. Energy resources are grouped into five categories. Regional economics are disaggregated by sector, each sector having its own capital stock. Agriculture is divided into five categories and trade is made up of fifteen categories. It is due to this great amount of disaggregation that the WIM is very complex and difficult to understand.

Level of Aggregation of WIM

Mesarovic and Pestel chose to represent the world system in terms of interdependent subsystems, termed regions. Their rationale for this approach was that it was essential to account for the variety of political, economic, and cultural patterns prevailing within the world system. The modelers felt that a regional outlook was imperative and that a homogeneous approach was misleading in not representing the world system correctly in the way it operates. The regionalization was determined by considering shared tradition, history and style of life, the stage of economic development, sociopolitical arrangements and the commonality of major problems which will eventually be encountered by the nations. WIM has twelve basic regions: (1) North America, (2) Western Europe, (3) Pacific Developed Countries (primarily Japan), (4) the Rest of the Developed World, including Australia, New Zealand, and South Africa, (5) Eastern Europe and the Soviet Union, (6) Latin America, (7) Middle East oil producers, (8) Non-oil-producing Arab

Countries, (9) Africa, (10) South Asia, (11) Southeast Asia, and (12) China.

The original Mesarovic and Pestel world model had only ten regions. The changes have been to subdivide the original North Africa and Middle East region into the OPEC and non-OPEC members of the region, and to subdivide South and Southeast Asia into South Asia (including primarily India, Pakistan, and Bangladesh) and Southeast Asia, including Indonesia. In the process of subdividing South and Southeast Asia into two regions, Taiwan, Singapore, and Hong Kong were changed in membership in a Pacific Developed Region with Japan.

The reasons for these newer subdivisions are fairly straightforward. The North Africa and Middle East region proved to be a bad combination of increasingly wealthy oil-producing countries and countries, such as Egypt, with little in the way of natural resources and national exports. South and Southeast Asia had also proven to be too highly aggregated. It combined the very highly populated and substantial food importing countries like India and Bangladesh with agricultural exporting countries like Thailand. In order to allow for more efficient analysis of the world food and energy issues, the modelers decided to subdivide the two regions.

Because nation-states still constitute the major units in the international system, the modelers realized that most of the problems to be analyzed and most of the support for their analysis would come from individual countries. Therefore, within the WIM it is possible to divide any one region into as many as five subregions. The regions which have been subdivided and their subregions are (1) North America into the United States and Canada, (2) Western Europe into the United Kingdom, West Germany, France, and the Rest of the European Community, and the Rest of Western Europe, (3) the Middle East Oil-producing Region into Iran, Saudi Arabia, the Gulf States, Iraq, and Libya/ Algeria, (4) Latin America into Mexico, Venezuela, Brazil/Paraguay, Argentina/Uruguay, the Rest of the Andean Pack Countries, Central America, and the Caribbean Region, and (5) Africa into Nigeria, West Africa, East Africa, Central Africa, and the Sahel.

Time Horizon of WIM

The WIM's time horizon concentrates on the period from 1975 to 2025. The WIM cycles annually and is initialized with 1975 data. The structure of the model allows the output of information in any multiple of a year. It also allows the user to move progressively forward in time. For example, the user could interact with the model just through 1980 until a satisfactory scenario were developed and then build on this by focusing on the 1980-1985 period.

Major Model Sectors of WIM

The major submodels within the WIM are population, economics, energy, agriculture, materials, machinery, labor/education, trade and payments, and aid/loans. These submodels are characterized by Mesarovic and Pestel in the following manner (Hughes, 1980):

1. Population. Originally this was a simple total population growth model and was then upgraded to represent several age cohorts. It now represents eighty-seven age cohorts

with age-specific fertility and mortality distributions. All individuals 86 years old and older fall into the top cohort. Fertility and mortality distributions change over time in response to a variety of endogenous and exogenous factors.

2. Economics. This submodel also grew until it currently represents seven economic sectors for all regions, and has been expanded further for specific analysis of individual countries. The seven sectors are agriculture, extraction, manufacturing, construction, transportation/communication, wholesale/retail trade, and services. Although some world models have more sectors, WIM has chosen to further elaborate these basic ones with "physical" models as described below.
3. Energy. Production, consumption, and pricing are represented for five energy categories: oil, gas, coal, hydroelectric power, and nuclear energy. Physical resources are an important element of this submodel.
4. Agriculture. Production, consumption, and pricing are represented for five agricultural categories: grains, nongrains, industrial crops, livestock, and fish. Land is represented in three categories: dry cultivated, irrigated, and grazing.
5. Materials. Production, consumption, and pricing are represented for aluminum, copper, and iron/steel. Again resource bases are important variables.
6. Machinery. The less developed countries (LDCs) face trade-offs between imports of consumer goods, food, important raw materials including energy, and capital equipment. Because of the importance of machinery imports in economic growth, WIM models machinery production and consumption explicitly.
7. Labor/Education. WIM represents the availability of and demand for labor in four education-related categories: unskilled, semiskilled, skilled, and professional.
8. Trade and payments. All the economic sectors and commodities from the physical models enter into trade. Trade volumes in different categories are related not just through the complementarity or substitutability of the goods in importing and exporting regions, but also through the trade and payments balances of regions.
9. Aid/Loans. Major intergovernmental transfers such as aid, loans, and repayments constitute the key noncommercial component of payments balances and are represented in WIM. This submodel is also used to represent nongovernmental financial transfers. (pp. 28-29)

Each of these submodels will be discussed in further detail later in this chapter. Because of the large size of the entire system, all of the full submodels have never been linked at one time. However, it is only necessary to eliminate one of them, generally labor/education or materials, in order to use the system. With the increase in computer technology, the ability to use all submodels also increases. The WIM increasingly allows selection of submodels at varying levels of complexity.

WIM portrays these nine physical submodels as partial economic equilibrium models. There are supply and demand sides in each of the physical models. Excess supply or demand is calculated for each category, and prices are adjusted upward or downward as required to move toward equilibrium. However, the submodels function under dynamic equilibrium which means that in each time period a step is taken toward equilibrium. This action in turn changes the market conditions and places the elusive point of balance of supply and demand out of reach. In effect, the model is constantly chasing equilibrium.

Interaction of the Submodels of WIM

The model's structure is greatly influenced by the multilevel hierarchical systems theory of the modelers. Figure 3-3 illustrates the initial and continuing conceptual framework of the model. To the left is the hierarchy of strata as explained earlier. The technological stratum serves as an interface between the deomographic-economic stratum and the environmental stratum. It incorporates the technologies which humans have developed in large part to be able to manipulate and

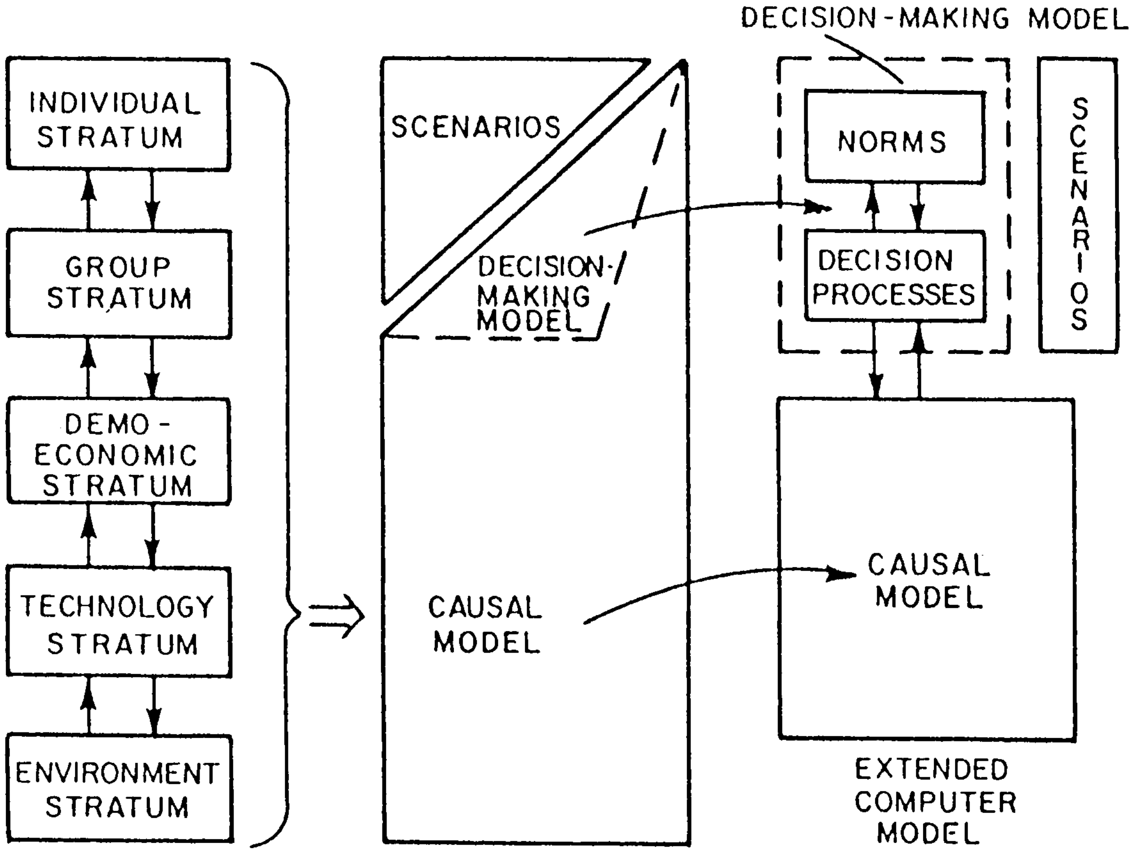

Figure 3.3. Multilevel hierarchical structure.

Source: Mankind at the Turning Point (p. 50) by Mihajlo Mesarovic and Eduard Pestel, 1974, New York: E. P. Dutton. Copyright 1974 by Mihajlo Mesarovic and Eduard Pestel.

control the environment. Simultaneously, the physical laws and resources in the environment work to constrain those technologies. The demographic-economic stratum represents more human elements in the development system. The economic stratum includes the entire financial and monetary structure which has been developed to increase people's capability to deal effectively with their technological and physical environment. Included in the group stratum are the sociological and political processes. The higher the stratum is in the hierarchical order the harder it is to represent physically in the model.

The second column of Figure 3-3 illustrates that the modelers felt it was not wise to represent all elements of any stratum within the computer model, especially those of the two highest layers. Instead Mesarovic and Pestel transposed the various strata into two major components of the actual model. First, is the "causal" model. This is the computer portion of the representation. This represents most aspects of the lower strata. The WIM was developed with "open loops" to represent the higher strata of the system. This is accomplished through the creation of an interactive computer system in which scenarios can be developed to represent decision-making processes and by which these scenarios can be quickly and flexibly introduced into the model.

Finally column three of Figure 3-3 represents the extended computer model. At the base, the causal model represents for the most part the demographic-economic, the technological, and the environmental strata. Above that, and introduced into the model through scenarios, are the decision processes and the norms or values which guide those processes coming from the group and individual strata.

The WIM employs closed loops to represent societal and political processes in individual aspects of the lower strata. These loops have been updated in the latest version of WIM. For instance, initially the loop which alters fertility patterns in the society was completely open and only scenarios affected fertility patterns. More recently WIM relies on a relationship between income levels of the society and the pattern of fertility. This loop represents the change in values and decisions regarding family size which occurs as family incomes rise.

While using the WIM it is advantageous to maintain the scenario techniques, since WIM allows external scenario development at all layers of the model. Therefore, nearly every parameter and many relationships are subject to change by the model user in the scenario process.

Figure 3-4 illustrates the elements incorporated in the causal model. This is the representation of the computer portion of the world model system. The major submodels are all included. The multilevel hierarchical conceptual framework is also represented. Specifically, on the highest level are the labor/education and aid/loans submodels. These two submodels represent the greatest amount of personal and group decision making. On the next level the population and economic submodels represent the demographic and economic stratum. At the lowest level are the four physical or commodities submodels, (materials, energy, food, and machinery) incorporating elements in every case of both the technological and environmental strata. As a type of interface

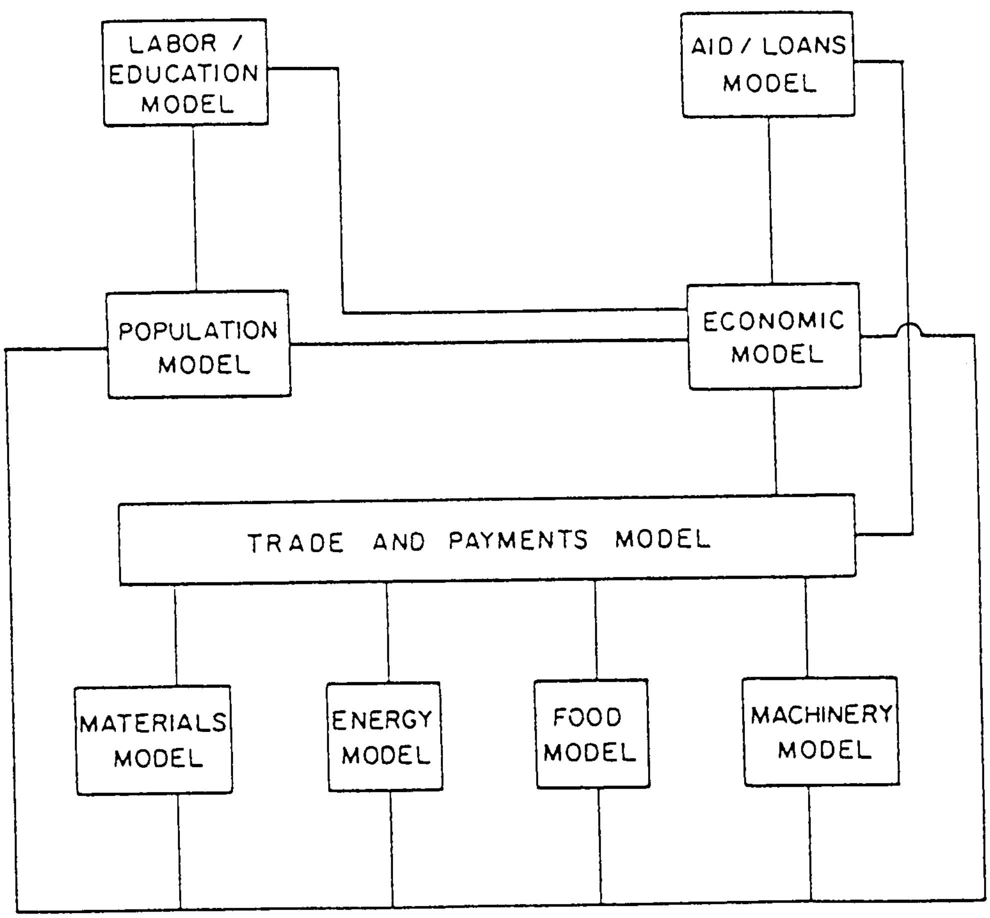

Figure 3-4. Major elements of the World Integrated Model.

Source: World Modeling (p. 33) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

between the economic model and the physical or commodities models is a trade and payments model.

Within the model structure there is heavy reliance on open-loop and threshold specifications of causal relationships crossing submodel boundaries. Specifically, many linkages only become important, or significantly change, when crises arise in submodels. Many social and political decisions cannot be represented in the causal portion of the model. Linkages of the social and political levels to other strata, and many linkages among strata, should be open to user specification. In general, linkages between submodels have received less theoretical and empirical attention than linkages within submodels, reinforcing the decision to allow user specification.

Flow of Calculations of WIM

Within any single time cycle of WIM the equations are computed sequentially rather than simultaneously. Figure 3-5 shows the sequence of references to various submodels in any given time step or iteration of the world model. The first submodel used is population. It is used at the beginning of every year or time cycle to compute the food demand for the population. The model later returns to the population submodel to compare food demand with actual food availability and to compute births and deaths. The second submodel used is labor/education. This provides information about the labor supply by category of education. The flow moves on to the economic submodel which calculates the production capacity of each economic sector, and also computes

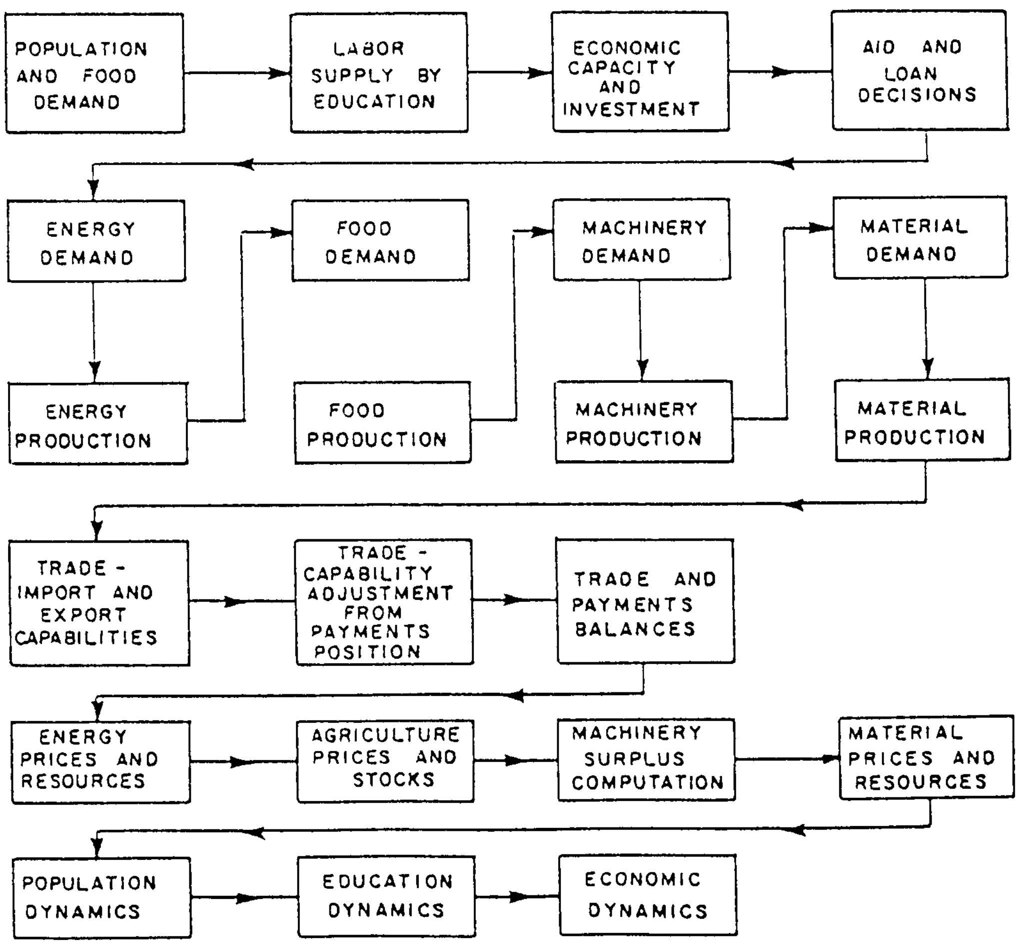

Figure 3-5. Sequential flow of the World Integrated Model.

Source: World Modeling (p. 38) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

the level of savings generated within the economy. The model later returns to this sector to see whether other factors allow production at full capacity and to calculate the actual level of investment in the economy as well as the destination of that investment by economic sector. The flow then moves to the aid/loans submodel in which aid and loan decisions are made on an annual basis. It is also here that loan repayment calculations are made.

The model flow next moves to the lower strata of the system which basically consists of the physical or commodities submodels. Specifically, the flow moves in turn through energy demand and energy production, food demand and food production, and similarly through the machinery and materials submodels. In each case the model computes not final demand or final supply but rather constant price demand and production capability. However, final demand and final supply on a global basis must balance, and part of this balance is achieved through trade.

The trade submodel first computes the import and export capabilities or demand of each region for each commodity. These capabilities and demands are calculated purely on the basis of what the regional populations and economies would like to import or export. There is, however, a considerable financial element to world trade and it is not always possible, particularly in less-developed countries, to import all those goods and services required or demanded by the population and the economy for lack of foreign reserves or exchange. Thus the model adjusts the demand for imports or the capability to export as a result of the regional payments position. Finally, on the trade level, the model calculates actual trade and world balances.

The process of computing these balances provides the information required to move back to the physical or commodity level, and to compute excess supply or demand. After moving through these calculations for energy, agriculture, machinery, and materials, the model returns to the submodels of the higher strata of the model. Given the actual food availability through domestic production and trade and given the internal population dynamics, it is possible to calculate the number of births and deaths and so update the population by age category. The education dynamics provide information on the surpluses or deficits in the labor supply. Finally, flow moves again to the economic model to record the impacts of surpluses, deficits, and price changes, and to calculate the level of investment in each economic sector.

Population Submodel of WIM

The population submodel contains eighty-seven categories of age distributions which are maintained for each region over time. The submodel relies on the cohort-component method in determining the number of births and deaths in a year. The only independent variable represented endogenously is income. The flowchart in Figure 3-6 illustrates the structure of the population submodel. The symbols for this and all other flowcharts are displayed in Appendix C. The major objective in the population submodel is to record over time the size of the population by age category.

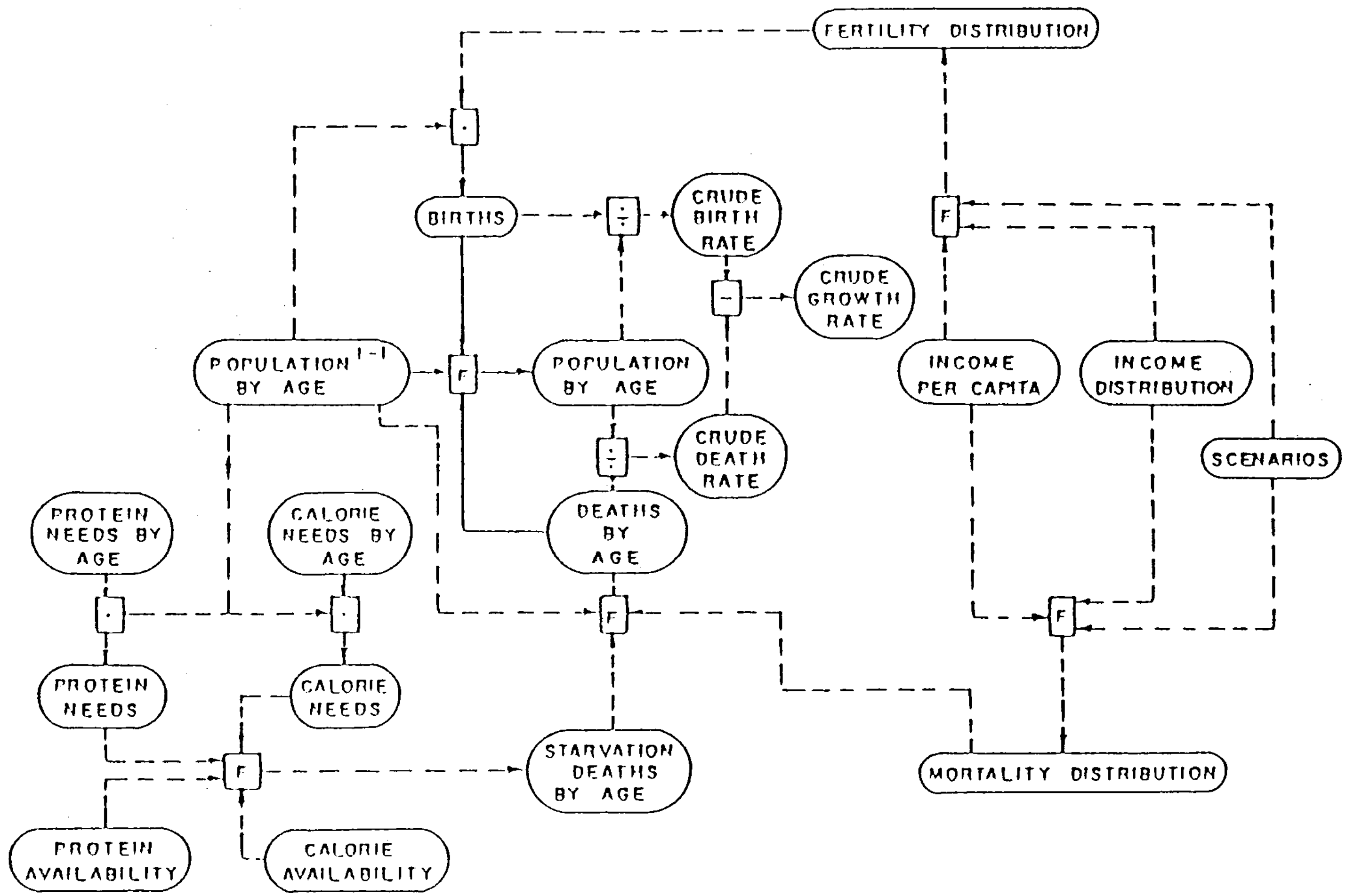

Figure 3-6. Population submodel of the World Integrated Model.

Source: World Modeling (p. 48) by Barry B. Hughes, 1980, Lexington, Massachusetts: D C. Heath & Co.

Age distribution. The center of Figure 3-6 illustrates that the population by age category in the WIM is a function of the population in the previous year and of births and deaths. Specifically, the births are added to the bottom category of the distribution and the deaths are subtracted from the appropriate age categories. Each category of the age distribution is advanced up the distribution as time passes.

Fertility distribution. Over time the shape of the fertility distribution changes. The model represents three processes for change in the distribution. First, the scenario can be altered to change the fertility rate so as to reach an equilibrium rate over an exogenously specified number of years. Secondly, the fertility distribution can be changed through its relationship with per capita income. This relationship involves two levels. The first level begins the transition from traditional or high fertility levels to modern or low patterns and occurs somewhat after mortality begins to decrease. The second level occurs when the demographic transition is complete and fertility stabilizes. WIM assumes that all regions have reached the lower level and relies on regionally specific exogenous upper levels of income ranges to compute the transition period fertility distribution by linearly interpolating between the initial distribution of the region and that of Western Europe (a region which has effectively completed the transition).

Income distribution also has an impact on the fertility level and interacts with the income per capita in the production of the impact. Specifically, more equal income distributions accelerate the movement toward equilibrium fertility. The two income factors result in a fertility distribution multiplier which takes on values between zero and one, and which describes the movement of the regional distribution from its initial condition to that of Western Europe. The multiplier is a function of the gross regional product per capita, the threshold value for completion of the transition, and the Gini coefficient[1] of income distribution, compared to that of Western Europe. So the model assumes linear interpolation during the transition period which is accelerated or decelerated by the income distribution.

Lastly, the model computes the fertility distribution taking into account the initial regional fertility distribution, and the Western European distribution, and the three variables mentioned above that relate to the fertility distribution multiplier. The multiplier from exogenous family planning scenarios does not affect the shape of the fertility

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[1] The Gini coefficient is one of five summary statistics of inequality used most commonly in empirical work. The other four include:

1. The variance.
2. The coefficient of variation.
3. The relative mean deviation.
4. The standard deviation of logarithms.

The Gini coefficient can be better understood when examining the relative sensitivity of these measures at different income levels resulting in the following tendencies:

1. The use of the variance implies increasing inequality-aversion.
2. The relative mean deviation is not strictly concave and is not sensitive to transfers on the same side of the mean.
3. The coefficient of variation attaches equal weight to transfers at different income levels, while the Gini coefficient attaches more weight to transfers affecting middle-income classes and the standard deviation weights transfers at the lower end more heavily.

distribution, only the total number of births it generates. This is based on the assumption that only the intensity of family planning programs is changing, not the basic society. As income changes, however, many aspects of society do as well, and the shape of the fertility distribution does change. This is represented by having the two income variables move not only total fertility toward that of Western Europe but the distribution shape as well.

Mortality distribution. The initial mortality distribution, like the fertility distribution, changes in response to three factors. First, scenarios about medical advances or setbacks in disease control result in an exogenous multiplier of mortality. When combined with a term that corrects for any initial discrepancies between the empirical crude death rate of the region and initial calculated deaths, it results in a mortality distribution multiplier.

The second factor affecting the mortality distribution is per capita income. All regions are beyond the threshold at which the mortality transition begins, and the model relies on an exogenously specified upper threshold of the transition. The transition speed is modified by a third factor, the ratio of the income distribution in Western Europe to that of the region. The two factors together result in a second mortality distribution multiplier which describes the progress from the initial regional mortality distribution toward one in which the transition is complete. All three factors come together in the computation of the mortality distribution. Again the model relies on Western Europe as a model for a region with a completed mortality transition.

Starvation. Unlike other global models, WIM has made feedback from food shortages age dependent. Both food requirements and susceptibility to shortages are age dependent. Specifically, starvation deaths depend on age-specific susceptibility to calorie and protein starvation factors which may be zero or positive. The starvation factors represent the fraction of the population which would starve in a given time period. It is assumed that the same people face both calorie and protein shortages, so deaths are computed as the maximum from either rather than the sum of both.

The calculation of both the calorie and protein starvation factors depends on comparison of the need and the availability of calories and protein. These availabilities are determined in the agricultural submodel. The needs depend on the population as represented in the age distribution, the age-specific requirements for calories and proteins, and regional variations in needs as a result of climate and physical size.

Indicators and linkage to other submodels. The population submodel also computes a number of indicators. Some of these include the crude birth rate, the crude death rate, total population, and population growth rate by region and for the globe. The submodel also sums the regional deaths and total starvation deaths across age groups.

Labor/Education Submodel of WIM

The basic structure of the labor/education submodel in WIM is divided into three parts: (1) a demand section in which labor needs in four education/skill categories are calculated as a function of economic production levels, (2) a supply section representing the training of individuals by level of education, and (3) a balance and educational expenditures component in which labor/education demand is compared with supply, and educational expenditures are allocated by level of education. Throughout, labor is represented in four categories by education: individuals without education or unskilled labor, primary educated or semiskilled workers, secondary educated or skilled workers, and university educated or professional workers.

Figure 3-7 illustrates the flow of the labor/education submodel. The ultimate objective of the demand side (left side of figure) is computation of labor demand by level of education. Total labor demand for each unit of gross domestic product (GDP) is represented as a function of the GDP per capita and is computed in a table function. The proportions of demand falling into each educational level are also a function of GDP per capita, which is used as a surrogate for the economic development level. The total labor force depends on the population and labor participation rate. The supply of labor in each category (right side of figure) depends on the educational expenditures, which are divided among categories according to the demand pattern or exogenously. Labor supply and demand are compared in each category (center of

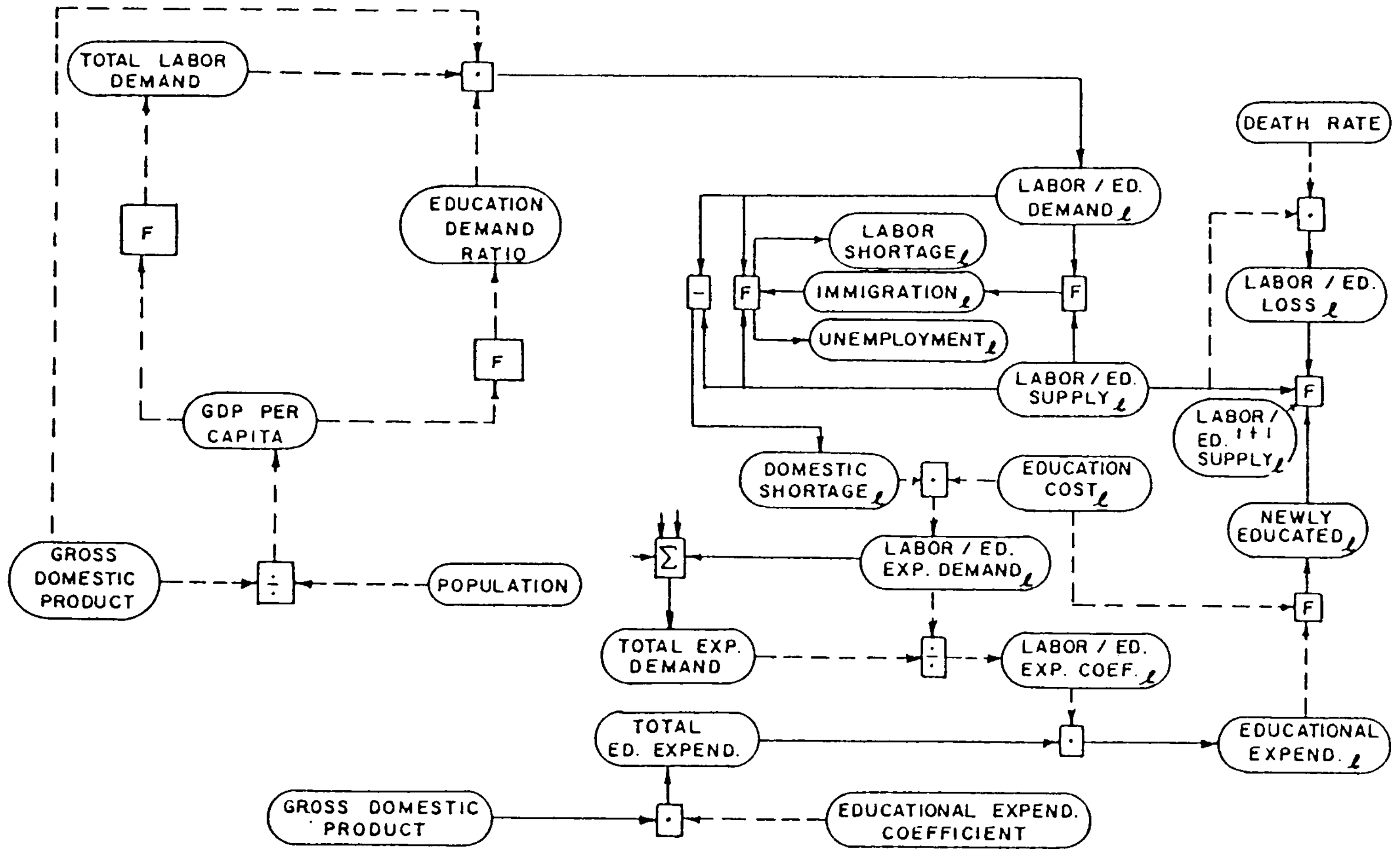

Figure 3-7. Labor/education submodel of the World Integrated Model.

Source: World Modeling (p. 57) by Barry B. Hughes, 1980, Lexington, Massachusetts D. C. Heath & Co.

figure). Although migration may help strike a balance, labor shortages or unemployment, and sometimes both, often persist.

Economic Submodel of WIM

Figure 3-8 shows the four major blocks of the core economic submodel and their general relationship with the rest of the model. The physical and commodities submodels (energy, agriculture, metals, and machinery) incorporate extended representations in physical form of components in the economic submodel. Although the physical and commodity submodels are partial equilibrium models, incorporating supply and demand sides with prices to clear the market, the core economic submodel is itself largely a supply-driven model. It represents available capital and productive capacity in seven sectors: agriculture, nonmanufacturing industrial, manufacturing, construction, wholesale/retail, transportation/communications, and services.

The initial expenditure components (private consumption, governmental consumption, investment, exports and imports) are based on the initial production calculations and on exogenously specified parameters, the most important of which is the savings rate. The actual translation of the savings into investment depends on the availability of capital equipment (machinery). Physical availability of investment by origin is recognized, though it is assumed that only machinery is a constraint. When model flow returns to the economic submodel, final expenditure components and production are calculated. The final calculations of the economic submodel accept total investment levels and the determination

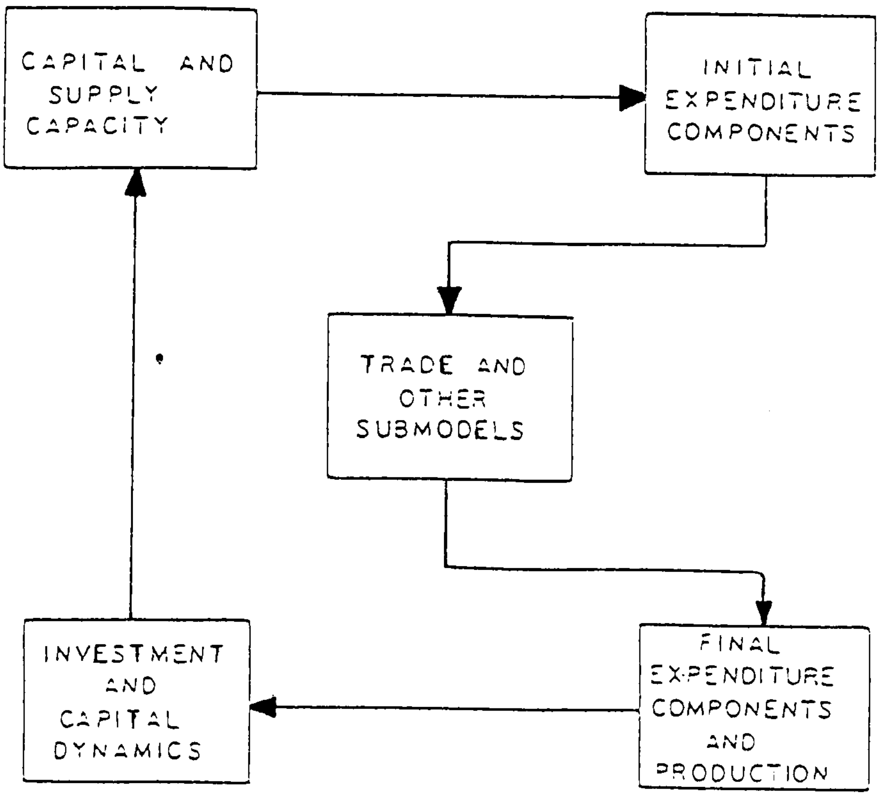

Figure 3-8. Economic submodel of the World Integrated Model.

Source: World Modeling (p. 72) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

of investment by destination in the physical models and produce the complete investment by destination vector. The capital dynamics update capital stocks for the next time cycle.

Supply. Figure 3-9 illustrates the flow pattern within the capital and supply capacity block of Figure 3-8. The final objective of the processes revealed in Figure 3-9 is the initial calculation of gross regional product (GRP) as shown at the bottom of the figure. There are two alternative mechanisms for the calculation of the initial GRP estimate. The simplest mechanism uses the Cobb-Douglas function. This function computes GRP as a coefficient multiplied by capital raised to the alpha and labor raised to the beta. Alpha and beta are exogenously specified, while the Cobb-Douglas coefficient itself can either be specified exogenously or computed within the model the first year.

WIM computes labor as a product of population and an exogenously specified labor population rate, adjusted by an exogenously specified value for net labor immigration. It should be possible to endogenously compute the labor participation rate as an increasing function of economic development. Unemployment levels determined in the labor/education submodel reduce effective labor supply, when that submodel is used.

The alternative to the Cobb-Douglas function and the procedure most often used is the sectoral computation of initial value addeds summing to obtain GRP. ALL value addeds but one are calculated by dividing the capital in the sector by a capital to output ratio. The

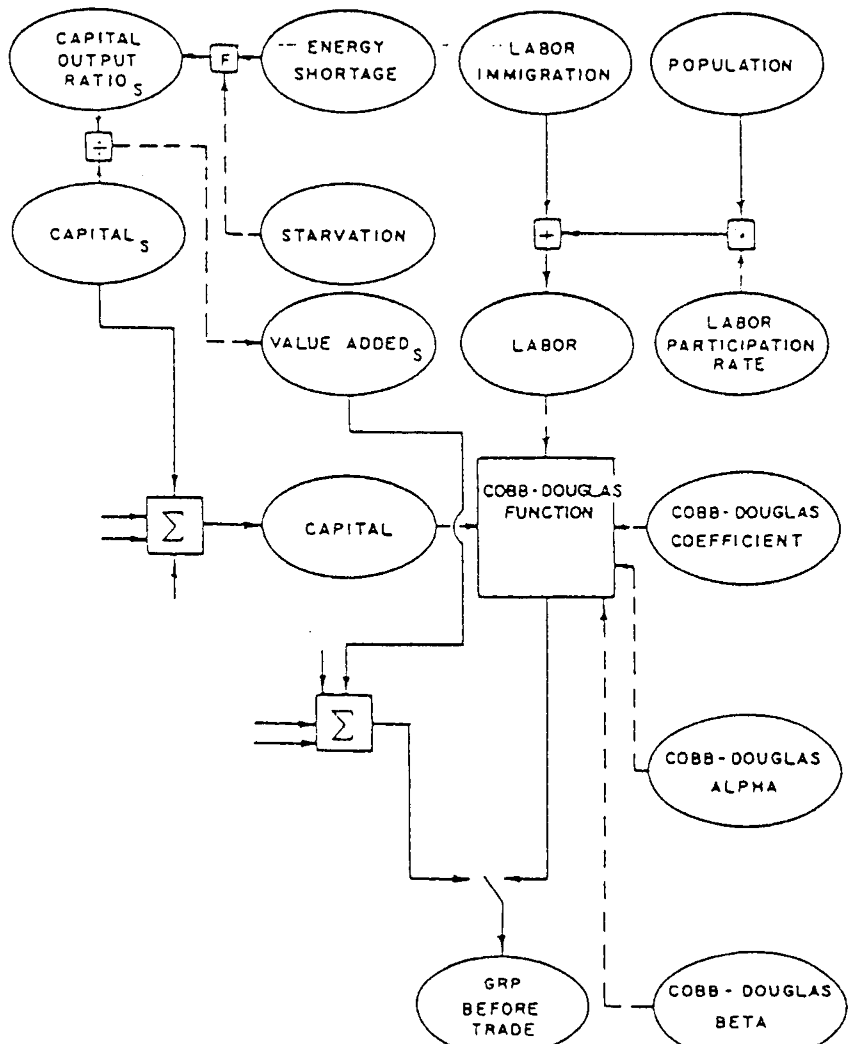

Figure 3-9. Economic supply of the World Integrated Model.

Source: World Modeling (p. 73) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

exception is the agricultural sector in which increases in value added over the base year are computed directly in the agricultural submodel. The basic capital/output ratios are specified exogenously but are multiplied in the model by factors representing the decreased productivity of capital as a result of energy shortage, if any, and also by starvation. Energy shortages reduce the productivity of capital by creating idle facilities, and any significant amount of starvation in a society would be socially disruptive and would also lead to lowered capital productivity. The exact relationship between starvation and the capital/output ratio is clearly speculative, however, and WIM incorporates it only as an alternative formulation to be used on a scenario basis. The impact can be increased, decreased, or eliminated by exogenous multipliers on the energy and starvation output reduction factors.

Initial expenditure components. WIM treats the production computed above as a target level. Actual production is dependent on what happens in other submodels, especially in trade. Final production levels may be higher or lower than the target values.

WIM computes initial values of all expenditure components based on the initial values of production and gross domestic product (GDP). This is accomplished through the use of coefficients of the expenditure shares. Historic data determines the initial values for the coefficients. WIM actually interprets the initial investment calculation as savings. The savings rate can be increased or decreased by an exogenously specified target or desired economic growth rate. Investment must be adequate to cover both depreciation in capital and the targeted growth in capital. Total capital lifetime depends on sectoral lifetimes and the overall depreciation rate. When the target growth rate is used, private consumption and governmental expenditures are commensurately adjusted in order to maintain the balance within the economy.

Final expenditure components. Figure 3-10 illustrates the initial calculation of expenditure components as described above along with the final calculation which will now be discussed. The economic submodel calculates initial estimates of total exports and imports. Exports and imports of machinery, energy, materials, food, and residual goods and services are calculated in the physical and trade submodels. The final values calculated in the trade submodel completely override the initial estimates of the economic submodel.

The original calculations of governmental expenditures, private consumption, and investment are modified by what occurs in the aid and loans model. When aid is given it must come from and go to somewhere within the economy. On the recipient side the aid bolsters either consumption or investment. Thus information from the aid and loans submodel allows calculation of the final value of governmental expenditures and private consumption, and of a revised figure for investment. That calculation for investment is not final and is essentially a monetary concept which must be compared with the physical availability of machinery. The comparison is made in the machinery and trade models. Those models accept the investment calculation from the economic model

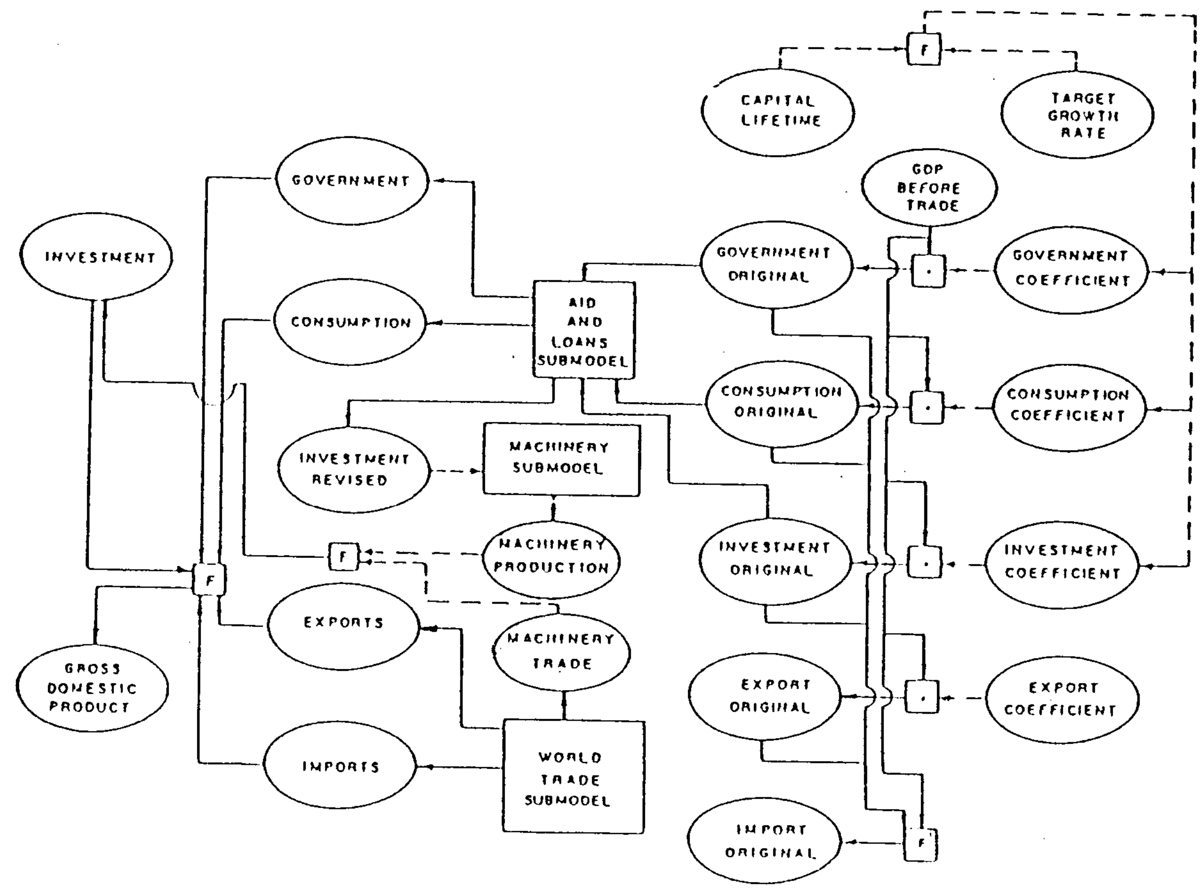

Figure 3-10. Economic expenditure components of the World Integrated Model.

Source: World Modeling (p. 77) by Barry B. Hughes, 1980, Lexington, Massachusetts D. C. Heath & Co.

as revised by aid and loans and compute actual domestic production of machinery and the levels of machinery imports and exports. Given these values, the intersectoral flows of machinery, and the proportion of investment constituted by machinery, the final investment level can be computed. This calculation assumes that nonmachinery portions of investment, primarily construction, will not be in short supply.

The final values of investment, consumption, and governmental expenditure, as well as exports and imports, are used to calculate gross regional product. The final value addeds are computed using initial value addeds and both initial and final gross regional products.

Investment and capital dynamics. Figure 3-11 shows the components involved in investment and capital dynamics. Here sectoral capitals are the functions of capitals in the current time step plus investment by destination and minus depreciation. Depreciation is capital divided by an exogenous capital lifetime. Capital stock is homogenous with respect to time but not with respect to economic sector.

The basic investment by destination demand for each sector is a normalized product of the total investment available and an investment by destination coefficient. This coefficient is computed on the basis of each sector's share in the economy, in a formulation which takes into account the lifetime of capital in each sector and the targeted sectoral economic growth rate.

In addition to information about the normal development of relative sector shares in the economy, the economic submodel has investment

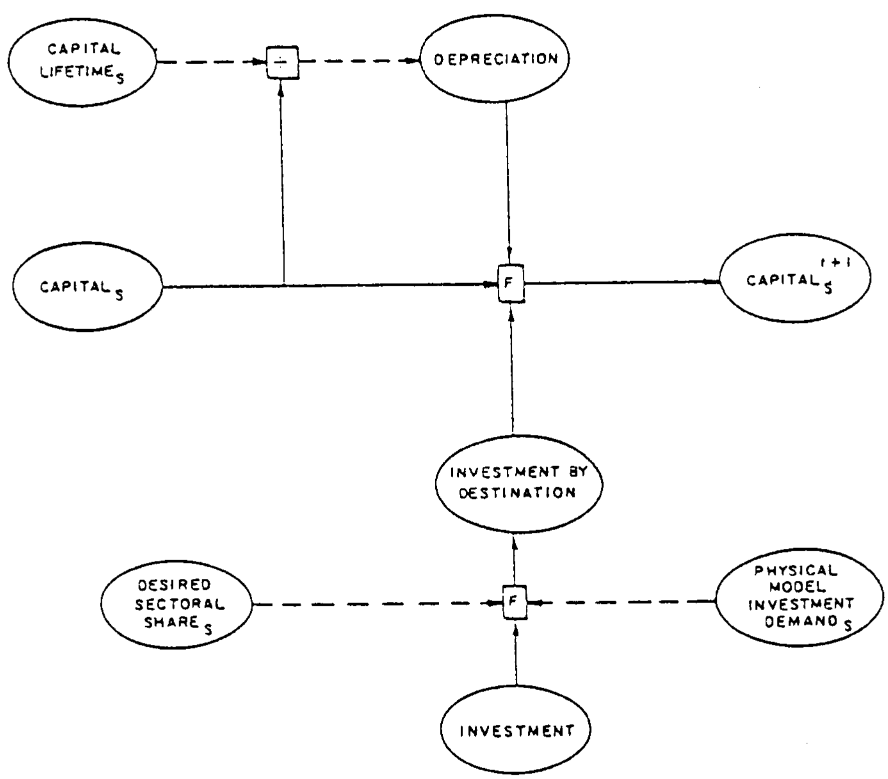

Figure 3-11. Economic investment and capital dynamics of the World Integrated Model.

Source: World Modeling (p. 79) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

demand information from the physical submodels. This information is transmitted to the economic model and is given priority over the basic investment by destination demand calculations. The investment demand computed in the agricultural sector completely supersedes the basic calculation in the economic model and becomes actual investment by destination. The investment by destination demand of the energy submodel determines large portions of the investment pattern in the nonmanufacturing industrial, manufacturing, and construction sectors of the economy. The portions are determined by coefficients allocating the energy investment demand among the three sectors. Investment with destinations not determined by the physical models is put into a pool of residual available investment. That basic investment by destination demand not satisfied by investment determinations in the physical models is put into a pool of residual investment demand. The final investment by destination for nonagricultural sectors is the basic demand level adjusted to take into account the ratio of residual investment available to residual investment. Those sectors receiving energy-related investments accept that as the base investment level and the ratio only adjusts remaining investment demand.

In summary, the process begins with total investment available, determined earlier on an investment by origin basis which specifically considered machinery availability. It allocates as much of this investment to the agricultural sector and the three sectors receiving energy investment as demanded on the basis of calculations in the agricultural and energy submodels. The residual investment demand of each sector is the difference between nonagricultural basic investment demand, determined from exogenously specified desired production sector shares, and the investment already allocated. The supply not yet committed is allocated among all nonagricultural sectors proportionally to the residual investment demand.

Indicators. The economic submodel also calculates a variety of indicators from basic variables. These indicators do not appear in the flowcharts for the submodel. The indicators include economic growth rate, GRP per capita, GRP growth rate per capita, consumption per capita, trade balance, global sums of imports, exports, capital, value added, and global economic growth rate.

Also not shown in the flowcharts is the availability of a nineteen-sector representation of the economy for any specified region. A seven-sector representation has been basic because UN National Accounts data are structured by the seven sectors and constitute the primary data base. There are some additional features in the nineteen-sector representation, including the possibility of representing production in each sector with a Cobb-Douglas equation, the representation of labor availability and energy demand on a sectoral basis, and the study of changes in labor and capital productivity on a sector by sector basis.

Energy Submodel of WIM

The energy submodel of WIM is a partial economic equilibrium model which represents regional production, consumption, and pricing in five categories: oil, gas, coal, hydroelectric power, and nuclear energy. Demand responds to changes in income and prices. Production capacity is based on investment in energy production facilities and the resulting capital accumulation over time. Investment decisions are a function of profit levels, surplus capacity, and reserve base. Known reserves change over time with discoveries and production levels. Prices change so as to minimize excess supply or demand.

Figure 3-12 illustrates the major components of the energy submodel. These are an energy demand section, and energy supply and resources section, an energy pricing component, and the world trade submodel which partly reconciles regional energy demand and energy supply in the short run. The world trade submodel also provides the size of excess demand or supply and this, in turn, affects the price of energy. Energy prices then feed back both to demand and supply. All physical or commodity submodels, including agriculture, materials, and investment goods, have a similar structure.

Demand. WIM approaches energy demand within the energy submodel in a statistical manner. First, a statistical procedure provides total energy demand. Its unique feature is a variable and endogenous representation of the income elasticity, a feature which is important in a model with a long time horizon over which levels of economic development change significantly. The second stage uses another statistical procedure to calculate type-specific energy demand.

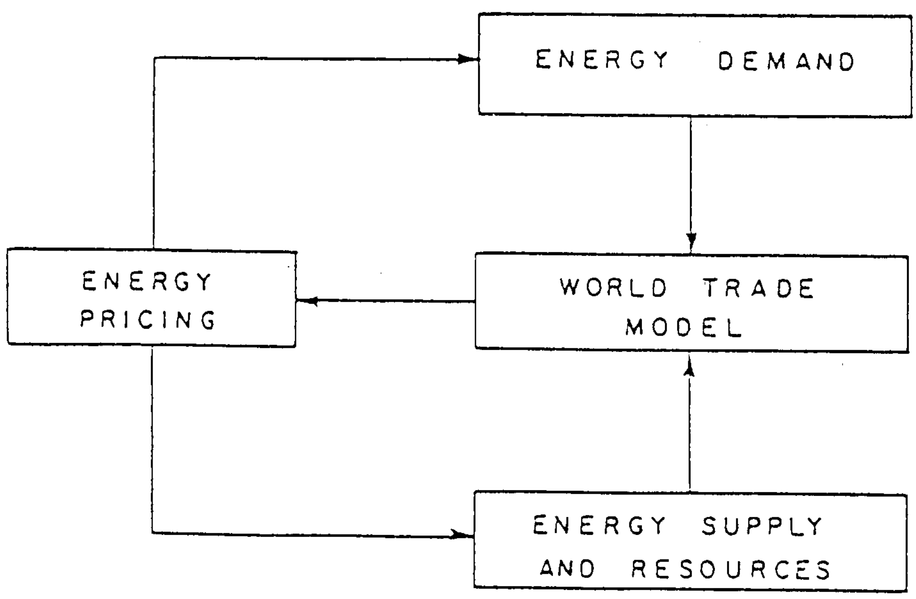

Figure 3-12. Energy submodel of the World Integrated Model.

Source: World Modeling (p. 94) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

Figure 3-13 outlines the structure of energy demand. Total energy demand is a price-modified product of the demand per unit of gross regional product and the total initial value of GRP. The demand per unit of GRP is not a constant, but is a function of the level of economic development of the society as represented by GRP per capita. This relationship has been captured in two table functions, one for the Western market economies and one for the centrally planned economies. A consumption weighted change in average energy price, based on individual energy prices, and in aggregate demand elasticity also affect the basic energy demand. Energy demand is computed from basic energy demand by allowing exogenously specified changes in energy demand as a result of noneconomic based conservation or technology changes and by adding a factor to adjust for the initial differences between the table function computed value and the empirical regional energy demand.

The next step is to divide total energy demand into demand by energy type. The model represents five types of energy: oil, natural gas, coal, hydroelectric power, and nuclear power. The basic procedure for division relies on an exogenously specified demand vector with five components which represents structural energy demand. Relative energy prices and a cross-demand elasticity modify this basic structural pattern. The structural energy demand vector is introduced exogenously and its changes over time represent scenario specification of technological and political developments.

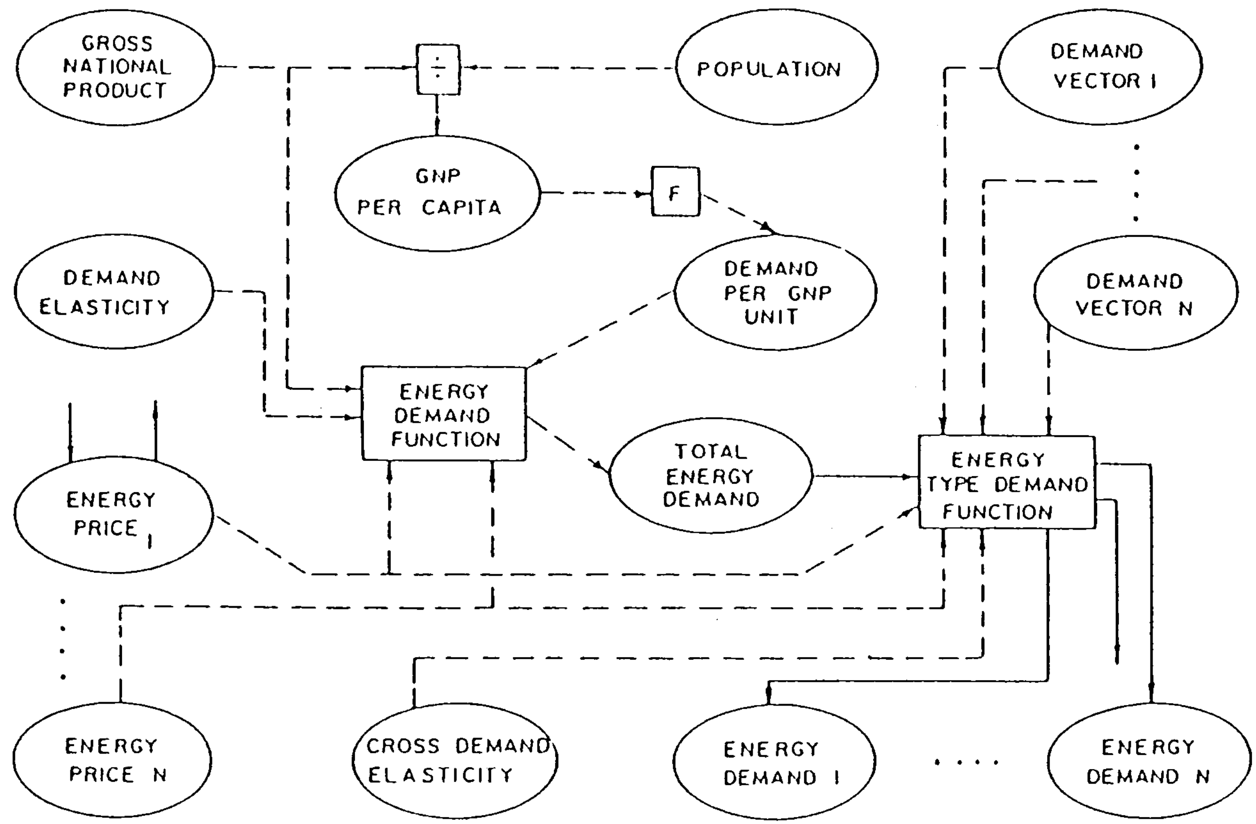

Figure 3-13. Energy demand in the World Integrated Model.

Source: World Modeling (p. 95) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

Supply. The WIM treatment of energy supply explicitly represents both investment and reserves. The investment calculation is a multi-stage procedure taking into account the inertia of investment decisions, profit levels, capacity utilization, and reserve availability. Given investment accumulation in energy capital, production capacity itself is a simple function of the capital stock. Reserves are also treated as a stock which increases with discovery and decreases with production.

Figure 3-14 shows the basic flow in the computation of energy production capacity, for a representative energy type. WIM makes a distinction between production capacity and actual production. The production capacity in any one time step is the quotient of capital in that energy type divided by a physical capital/output ratio. Capital is in turn a function of the capital in the preceding time step minus depreciation, which depends on the capital lifetime plus new investment.

The most important aspect of the supply model is the computation of new investment. Energy investment is a function of four factors: the basic trend of investment (representing cash flows and decision-making inertia), profit potential, surplus capacity, and resource availability. Trend line investment in each energy type is investment in the preceding time step times one plus the rate of economic growth in the economy. This normal or trend line investment pattern supposes that there is no difference between the energy sector and any other sector of the economy in profitability, capacity utilization, or raw material availability. There are modifications to the basic investment calculation. First, is a modification of investment as a result of the profit rate

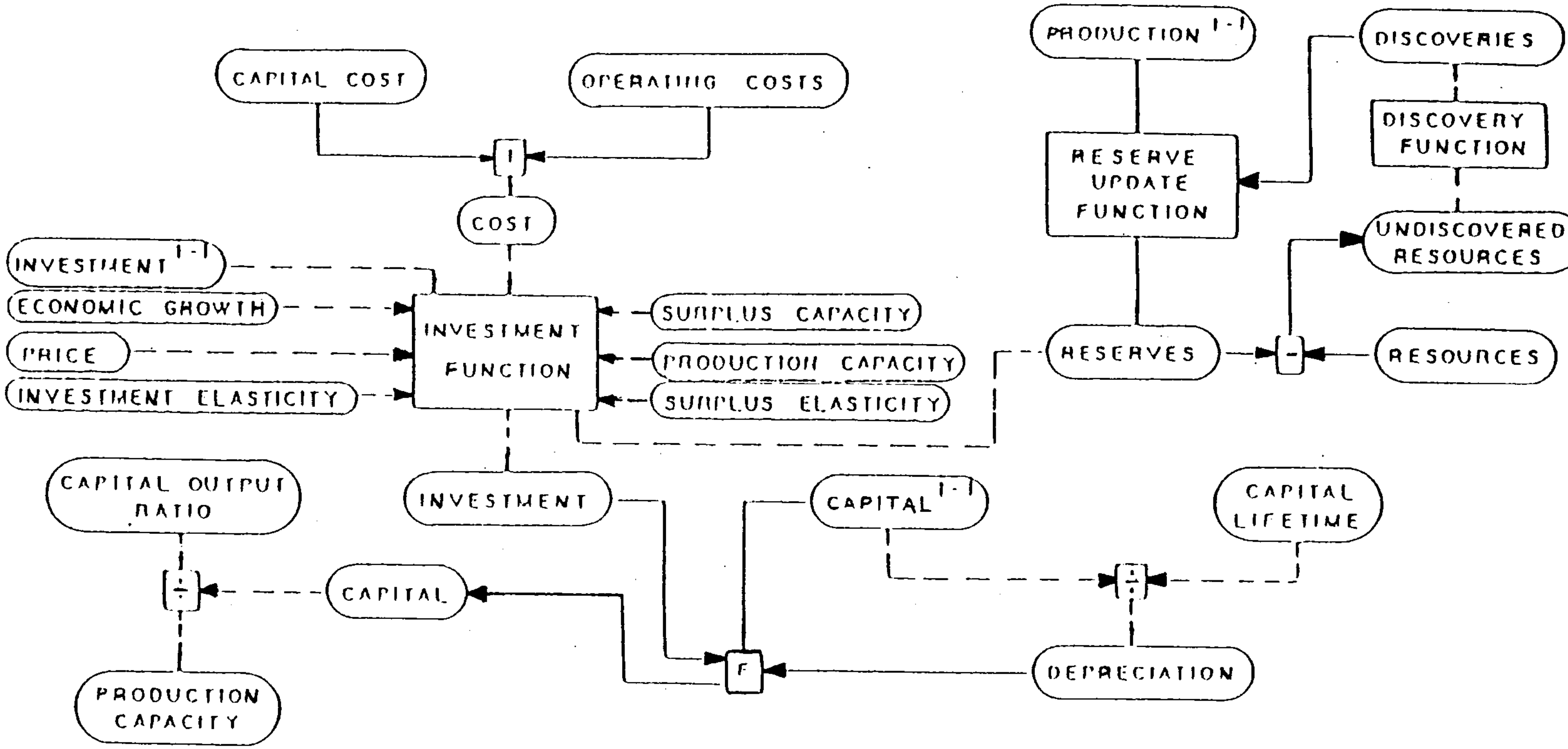

Figure 3-14. Energy supply and resources of the World Integrated Model.

Source: <u>World Modeling</u> (p. 98) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

available to the investor and an elasticity of investment with profit. The profit rate is the difference between price of energy and cost of energy divided by cost, where the sum of capital cost and operating cost constitutes cost. The first term of the capital cost is one plus a discount rate to a power which is the lifetime of the energy investment. These capital costs must be converted to a per barrel capital cost, which is done by multiplying them by the capital/output ratio. They must be further modified to represent the cost per annual barrel of energy output, which is done by dividing the cost by the lifetime of the energy capital. The entire capital cost term is increased to represent the impact of operating costs.

The second modification results from surplus capacity. When the surplus capacity is at or exceeds adequate level, a surplus elasticity restrains investment. The last factor modifying basic investment is the level of reserves. As the reserves to production/capacity ratio drops below a specified lower ratio, approximately ten to fifteen, investment begins to be constrained as a result of resource restraints.

There are two further scenario techniques for the manipulation of investment. The first involves the specification of an energy investment scenario factor which increases or decreases the level of investment for all energy types by a specified fraction. This would represent, for instance, additional or decreased investment as a result of taxation policies. Second, it is possible to directly specify the exact level of investment.

The energy supply portion of the submodel also contains the computation of reserves. Those resources which have not yet been discovered are computed as ultimate resources minus known reserves and cumulative production to date, and a discovery function is used to calculate annual discoveries. The rate of discovery is an increasing function over time from an initial base value and an annual increment rate, but is dampened as the amount yet to be discovered decreases. Annual discoveries are added to reserves, and annual production is subtracted from reserves in the reserve update function. Global discoveries are distributed among regions according to proportions of undiscovered resources in each region.

Supply/demand balance and prices. WIM represents energy as a partial equilibrium system. That is, both supply and demand are price responsive, and prices adjust so as to clear the market (balance supply and demand). Figure 3-15 summarizes the linkage of the supply and demand sides of the submodel through their interface with the trade submodel and indicates the price computation function. Production capacity and energy demand by energy type are compared, and the difference between them becomes either a net regional import demand or a net regional export capacity.

These values go to the world trade submodel, which will be described later. Two principal outputs of the world trade submodel for the energy submodel are imports and exports by energy type. These, in combination with production capacity, allow computation of final

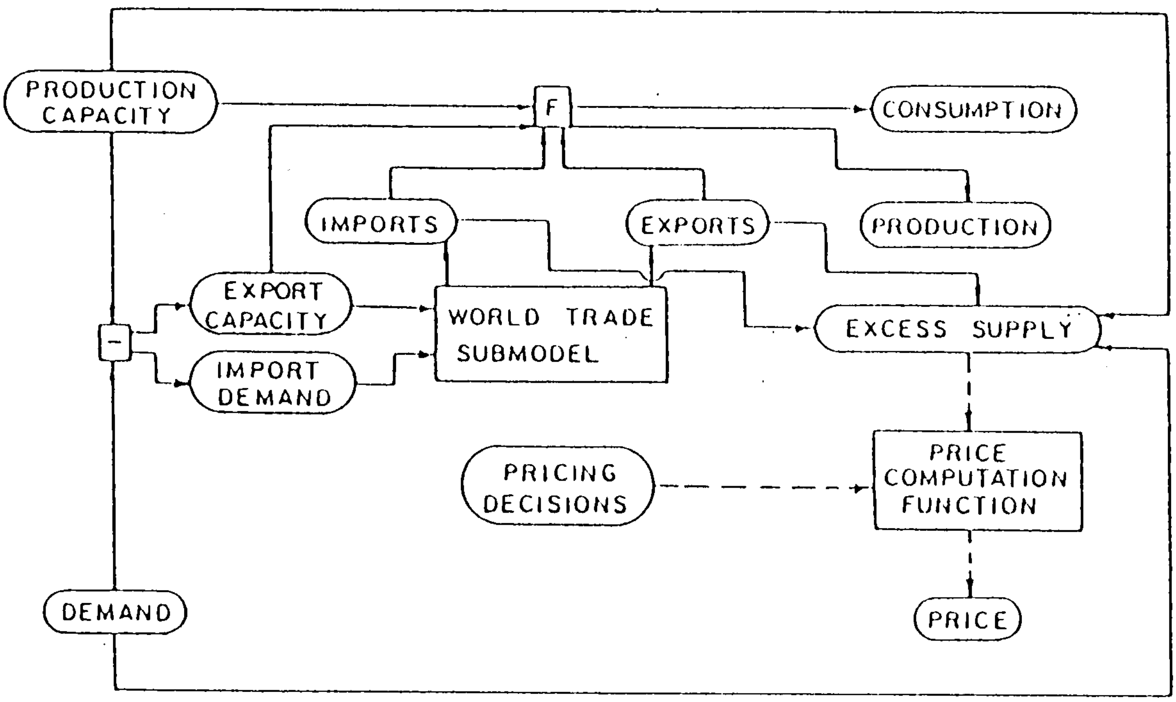

Figure 3-15. Energy trade and pricing of the World Integrated Model.

Source: World Modeling (p. 101) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

production and final consumption. Thus WIM makes a definite distinction between capacity for demand and final consumption. Although production and consumption are always equal, there may exist either excess supply capacity or unsatisfied demand. Based on outputs of the world trade submodel, it is possible to compute the excess supply or demand, also by energy type. Under normal conditions, the size of the excess supply or demand determines the magnitude and direction of price changes in a price computation function. WIM also introduces the possibility of price-setting decisions by any given region or regions and these then override the market clearing price.

The price computation function computes energy prices in a dynamic supply/demand equilibrium procedure, chasing equilibrium over time. Near exact market equilibrium could be achieved in every time step in an iterative computation procedure. It would, however, require more computation time. Moreover, the real market is not in exact equilibrium at any time point, because consumers and producers are always reacting without perfect knowledge and can only move the market toward equilibrium.

More specifically, energy prices are changed from energy prices in the preceding time cycle, depending on the adjusted excess supply or demand, the expected or targeted level of energy surplus, and a price adjustment coefficient. The expected level of surplus capacity represents the normal shut-in or uninitialized capacity. Thus upward pressure on prices exists well before demand exceeds 100 percent of capacity. The basic value of excess supply or demand is adjusted for exporting regions to represent the upward price pressure upon them when there is global excess demand. This is necessary because there will exist no basic excess demand for exporting regions; the model assumes they meet all of their domestic demand before exporting. To compensate for this, any global energy deficit, as represented by the difference between the world sums of export capacity and import demands, is allocated among the exporting regions proportionally to the ratio of regional exports to the global sum of exports. However, no change in prices takes place if the excess supply or demand is within an acceptable range around the desired or targeted surplus. This "dead-band" keeps the system from being overly sensitive to small changes.

Finally, oil prices are highly integrated globally, with the exporting regions situated as price givers and the importing regions as price takers. Thus for oil, prices in importing regions are set as the weighted average of prices among exporting regions.

Indicators and linkage to other submodels. The energy submodel also computes a number of indicators. These include global production capacity for each energy type, the global sum of all energy production capacity, the sum of capital in all energy types and all regions, global investment in energy, the total investment in energy of each region, the portion of total regional investment devoted to the energy sector, the energy demand per capita, and the ratio of energy demand to the size of the economy, and the total energy deficit of a region.

A number of indicators are produced for nuclear energy. These include the total number of nuclear plants in a region, the frequency of nuclear plant construction in order to maintain a given stock of plants, and finally, the world total of nuclear plants.

Two more indicators are computed for coal energy. These are the millions of coal cars which regional consumption could fill (as a rough indicator of the implications of coal consumption), and the cumulative additions of carbon to the world's atmosphere as a result of fossil fuel use.

There is an important direct linkage between the energy and economic submodels. The impact that an energy deficit will have on the economy is represented as a reduction in the capital/output ratio, representing inability to use capital effectively or at all when there is an energy shortage. The reduction in the capital/output ratio is a multiplier of the ratio in the economic submodel, and is computed as the ratio of the deficit to the total energy demand. The linkage can be intensified or weakened by an external parameter.external parameter. the ratio in the economic submodel, and is computed as the ratio of the deficit to the total energy demand. The linkage can be intensified or weakened by an external parameter.

Agriculture Submodel of WIM

The WIM agriculture submodel is a partial economic equilibrium model and represents production, consumption, and pricing in five agricultural categories: grain, nongrain, industrial crops, fish, and livestock. Demand responds to changes in income and prices. Production is based on the availability of land and agricultural capital over time. Investment decisions for land development and agricultural capital formation are a function of prices and potential return on investment. Land in production can be dry cultivated, irrigated, or grazing and is subject to competing demand from industrial/residential/recreational users. Prices change so as to minimize excess supply or demand.

Figure 3-16 shows the major components of the food and agriculture submodel. These are essentially identical to those of the energy submodel. The only difference is that the supply side shows investment and production separately. The reason for this is that production is somewhat more complicated in the food submodel. As with energy, supply and demand are brought into balance in the world trade submodel. The level of surplus or deficit in the system influences prices, which in turn feed back to influence demand and to influence investment in agriculture. This description of the agricultural submodel looks in turn at demand, supply (production and investment), and pricing.

Demand. Agricultural demand in WIM is made up of food, feed, and industrial demand. Food demand is computed on a per capita basis first. It responds to income and price changes. Feed demand is determined by the interaction of livestock herd size and grazing land potential. Industrial demand is responsive to industrial production levels and prices.

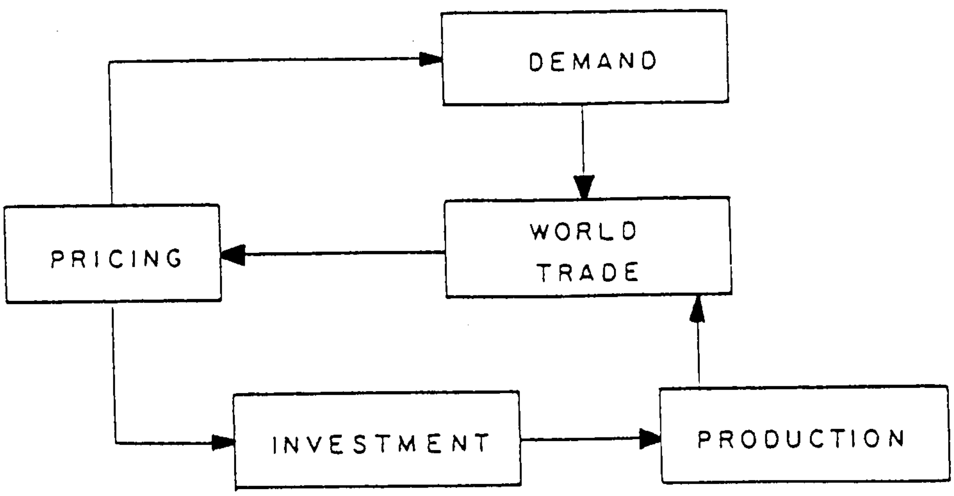

Figure 3-16. Agriculture submodel of the World Integrated Model.

Source: World Modeling (p. 116) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

The demand side of the agricultural submodel is represented in Figure 3-17. The middle of the figure indicates the structure of food demand, in which basic food demand per capita is computed first. It depends on the value in the previous time cycle and is modified by changes in GRP per capita, as a surrogate for income, and an income elasticity.

Although income elasticity can be an exogenous variable, the model will compute it for grains and livestock endogenously, unless overridden by an exogenous specification. It does so by using two table functions representing the relationships between income per capita and per capita grain or livestock assumption. Direct grain consumption increases with income at the lowest levels but is an inferior food and decreases with higher income; livestock consumption increases monotonically with income.

Substitutes among categories in response to relative price changes depend on a cross elasticity and on the change in the food category price from the first step relative to the change in a weighted average food price. The substitutions are constrained to cause no net increase or decrease in calorie consumption; that is, the sum of the products of substitutions with the calorie contents of the food types must be zero. The final value of per capita food demand is the basic value plus the substitutions across categories in response to price.

Feed demand depends on the size of the livestock herd and the food demand of the animals. Some of the herd is fed by grazing land,

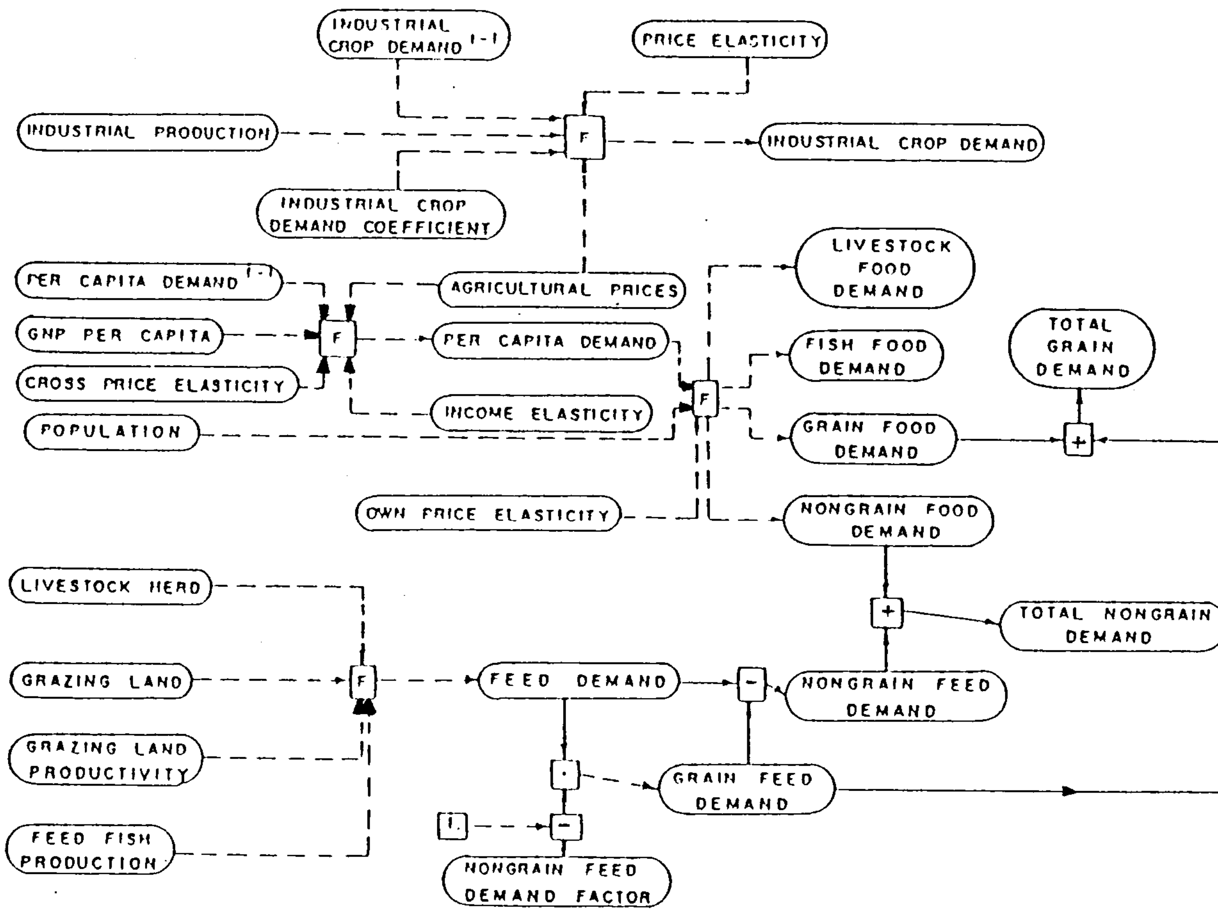

Figure 3-17. Agricultural demand in the World Integrated Model.

Source: World Modeling (p. 117) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

depending on the feed equivalent quality of the land. Some are also fed by use of a portion of fish production as livestock food supplement.

Industrial demand for agricultural production depends on the growth in the manufacturing sector of the economy, for which the model relies on value added in the third economic sector. Manufacturing sector growth increases industrial demand for agricultural population, depending on the fraction of the manufacturing sector requiring agricultural input and on an elasticity of demand with that growth. Industrial demand also varies with price changes and price elasticity of demand.

Total agricultural demand for grain is the sum of food demand plus a fraction of feed demand. The same is true for nongrain demand, to which the rest of the feed demand is assigned. Demand for industrial crops comes only from the industrial economy, while demand for livestock and fish comes only from food.

Supply. The presentation of supply has two components (see Figure 3-16). The first is production in any given time cycle and the second is capital formation.

Production. Crop production in WIM depends on land availability and yields. Land is treated as a stock. Yield depends on inputs and reflects decreasing marginal utility of inputs. Livestock production depends on the herd size and slaughter rate. Fish production depends on the maximum sustainable global fish catch and the regional share in the catch.

Figure 3-18 represents the production side of the model. There are three relatively independent components: crops, livestock, and fish. Agricultural production of crops depends ultimately on yields and land under cultivation, where the land under cultivation is divided among the three crop types: grains, nongrain, and industrial crops. The land itself falls into three categories (dry cultivated, irrigated, and grazing), only the first two of which are used in crop production. The division of land among different crop types varies over time, depending on the prices of those crops and an elasticity of land use.

The determination of crop yields is a two step procedure. The first step is to compute inputs to production (fertilizer and so forth) as a saturating exponential function of agricultural capital, modified by prices of food and inputs. The second step is to compute yield as a saturating exponential function of inputs.

Livestock and fish production functions are not as complex as those for crops. Agricultural production of livestock is simply the herd size times the slaughter rate. The slaughter rate varies over time with changes in the price of livestock and an elasticity of slaughter. Occasionally there is also hardship slaughter when feed supplies are inadequate. In the sequence of model calculations the feed demand is known early but feed supply is known only near the end of calculations. Thus hardship slaughter of livestock is added to food stocks for the next time cycle. The amount of hardship slaughter depends on the feed requirements of livestock. Updating the livestock herd itself requires knowledge of the reproduction rate, a function of changing

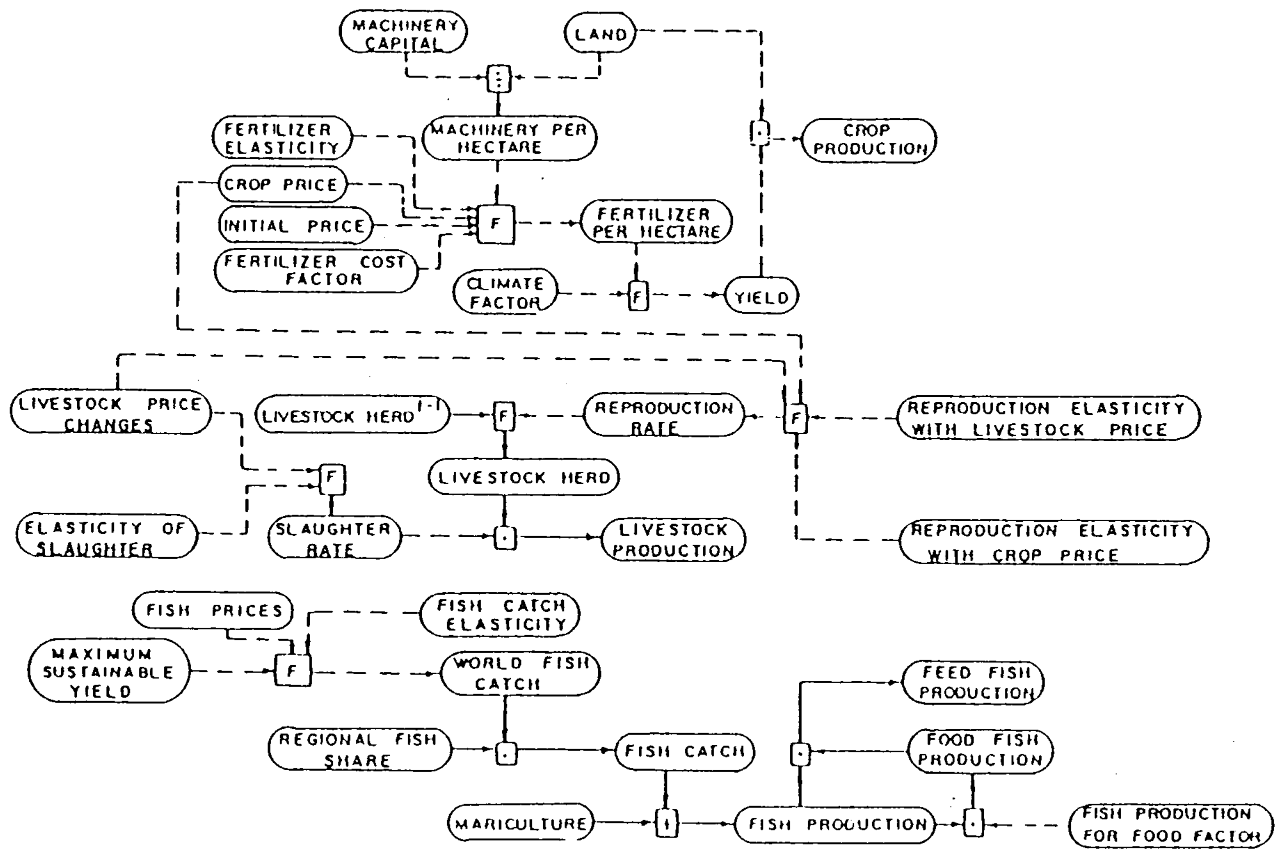

Figure 3-18. Agricultural production in the World Integrated Model.

Source: World Modeling (p. 121) by Barry B. Hughes, 1980, Lexington, Massachusetts. D. C. Heath & Co.

livestock prices and an elasticity, and also of changing grain prices and an elasticity.

Fish production combines fish catch and exogenously specified mariculture levels. Fish catch changes in increments dependent on time, the maximum sustainable world fish catch, the regional share of world fish catch, changing fish prices, and an elasticity of fish catch with changing prices.

Investment. Investment decisions in the agricultural submodel of WIM, like those in energy, depend on many factors, one of the most important of which is profitability. Other factors include decision-making inertia and political (exogenous) decisions. After determining the overall level of agricultural investment, WIM divides it between capital and land categories. Investment in land is further divided among land types. All the divisions of investment depend heavily on relative profitability.

Figure 3-19 illustrates the important investment portion of the agricultural submodel. Several factors affect the total investment level. All else equal, investment in agriculture will be the same proportion of total basic regional investment as in the preceding time step. The proportion changes with changes in food prices, productivity of investment, and fertilizer prices. It can also be increased or decreased exogenously to represent policy decisions. The price change factor depends on a production weighted price change and a price elasticity. The productivity of agricultural investment factors changes as yield

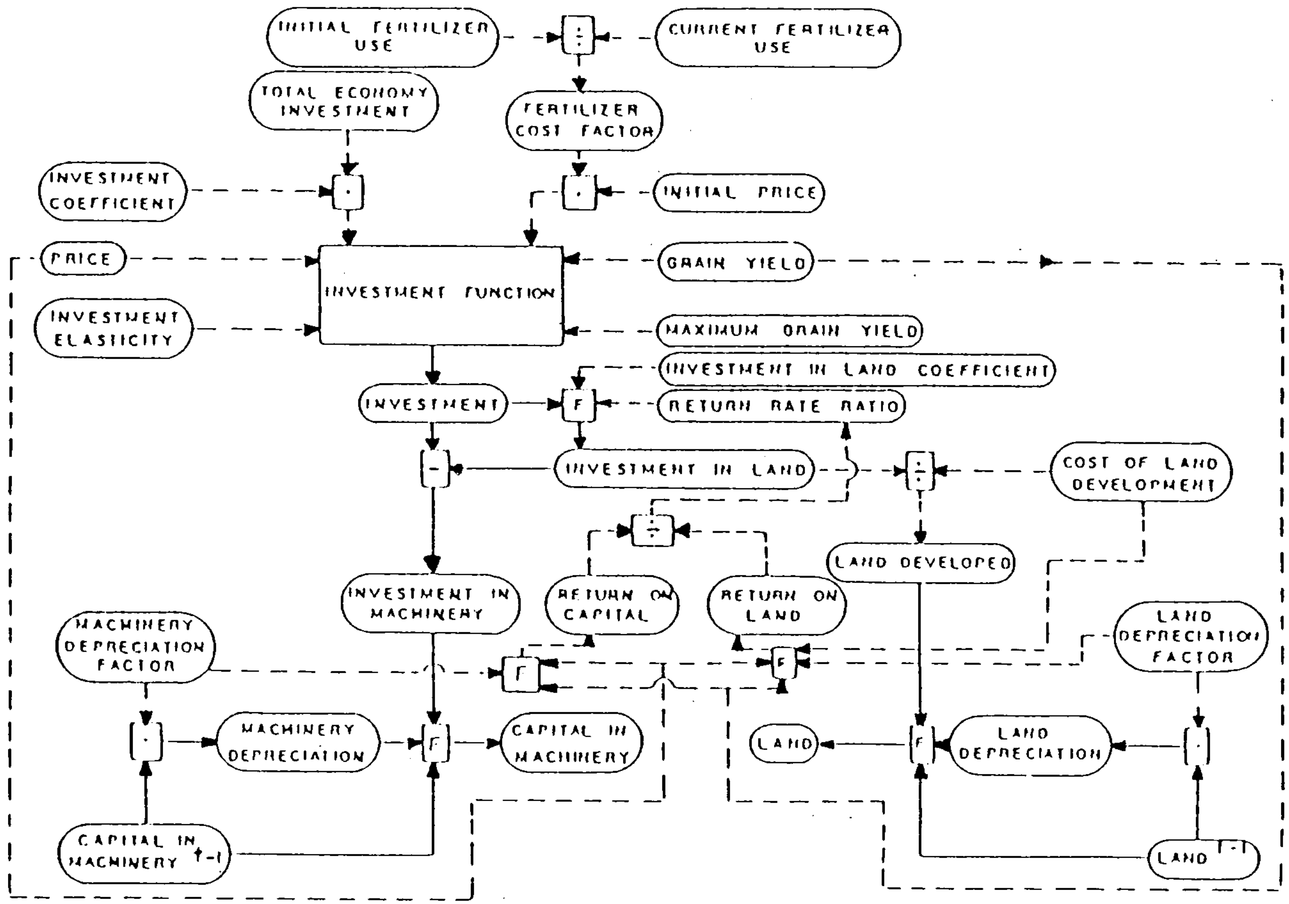

Figure 3-19. Agricultural investment in the World Integrated Model.

Source: <u>World Modeling</u> (p. 125) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

varies, going to zero as yield approaches yield maximum. The fertilizer price factor affects investment in agriculture when the gross expenditure on fertilizer changes as a portion of total agricultural investment. The relationship depends on an elasticity of investment with fertilizer expenditure. The proportion of agricultural investment in total investment can then be recalculated.

The next step is to split the agricultural investment among two categories: total investment in land and investment in agricultural capital. The basic proportion going into land is determined by a coefficient and will change only when the ratio of return on investment in land to that in capital changes from the initial conditions; the changing return rate affects investment through an elasticity of investment. The investment in agricultural capital is the residual.

The return on an additional unit of agricultural investment in land is a function of the cost of land development, the yield of land, the price of production from the land, and the lifetime of the investment or the inverse of annual land investment depreciation. In calculating return on land investment, dry cultivated land growing grain is assumed.

The return on a marginal investment in capital depends on the resulting increase in yield. It is calculated by multiplying the difference between the yield with the investment increment and that without it times land base, the price of food, and the lifetime of the investment, that is, the inverse of the annual depreciation of a capital investment. The agricultural stock grows with the investment and shrinks with the depreciation.

The distribution of investment to land is more complicated because it depends on both the relative cost and the relative productivity of different land categories. The average cost of land development increases exponentially as land already developed or withdrawn from cultivation reaches the maximum which can be developed. Land withdrawn changes with population increase and a coefficient representing the nonagricultural land requirements of each million individuals. In addition, land can be withdrawn from cultivation for soil bank.

The split of total land investment into investment for each land category depends on the coefficients of investment. The coefficients of investment in turn depend on exogenously specified initial values and the ratio of return on investment in each land category to its initial value. The calculation of return on investment in cultivated and irrigated land is the same as that for total land. For grazing land the productivity must be measured not in yield per hectare but in livestock grazed on a hectare of land and the calculation must consider the price of livestock.

Supply/demand balance and prices. Because the WIM agricultural submodel is a partial economic equilibrium system, both supply and demand are responsive to prices. Prices change over time in a constant search for a constantly elusive precise equilibrium. Trade plays an important role in the supply and demand balance.

Figure 3-20 depicts regional demand and supply, export and import capacities, and the linkage of the agricultural submodel to trade. It also represents the linkages from trade back to the agricultural submodel, especially the impact on diets and food price.

Basic net agricultural import demands and export capabilities depend on the regional demands, supplies, and stocks carried over from previous years. Some agricultural trade can be exogenously specified contract-based exports or imports and not enter into world trade computations. Contracts are excluded from final net import demand and export capacity. World trade computations produce agricultural imports and exports. These allow computation of total supply. Consumption is the minimum of demand and supply. When supply exceeds consumption, the difference becomes stocks for the next time cycle.

In the energy submodel regional prices were computed. In the agricultural submodel only global prices are computed. The global price for each agricultural commodity depends on the global demand and supply balance. World excess supply or demand of agricultural goods is world production plus world stocks minus world demand. The dividing line between upward and downward pressure on prices is not zero surplus but rather a small positive desired surplus. Moreover, price change depends not on the absolute magnitude of surplus or deficit, but on the fractional excess supply or demand. Thus for the purpose of computing price changes, fractional excess supply or demand is determined as a function of absolute excess supply or demand and the desired proportion of excess supply or demand.

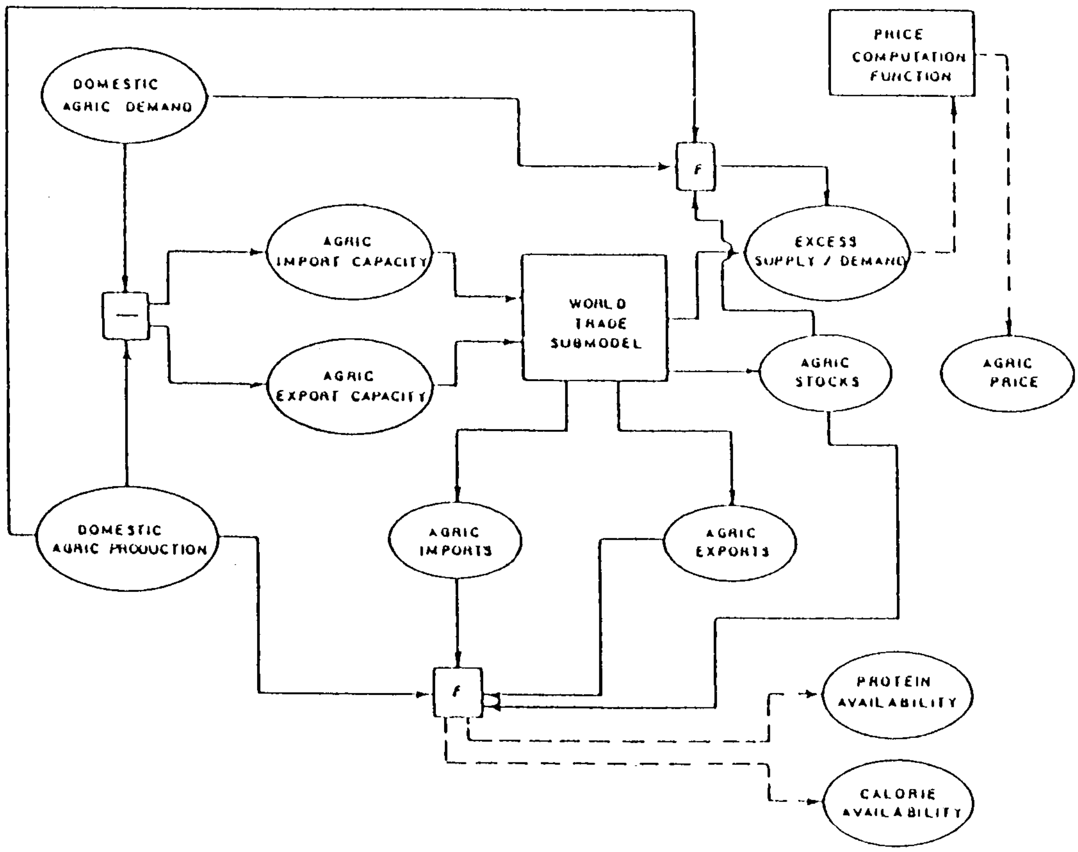

Figure 3-20. Agricultural trade in the World Integrated Model.

Source: World Modeling (p. 130) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

Agricultural prices change proportionally to the fractional excess supply or demand, the dependence being specified exogenously. Agricultural prices are more variable then energy prices (in the model and in the world) partly because of greater production variability. To avoid unduly great reaction by the model to short-term fluctuations in excess supply or demand, a second-order term has been added to the price calculation. That term applies a second price adjustment parameter to the change in the fractional supply or demand. Regional or domestic food prices are either globally determined or set by the model user to represent exogenously specified regional price support policies.

Indicators and linkage to other submodels. As shown in Figure 3-20 it is now also possible to compute calorie and protein availability as needed in the population submodel. First, per capita food consumption can be computed from each of the agricultural consumption values. Grain and nongrain consumption is divided between food and feed uses proportionally to food and feed demand. Feed availability can then be computed as residual consumption in the grain and nongrain categories. There is no food consumption of industrial crops, and all fish and livestock consumption are for food.

Total regional calorie and protein availability depend on the per capita food availabilities, the proportion of the food lost, and the calorie and protein contents of the food. These latter are computed in the first model time step, given initial regional calorie and protein availability and the proportions of the availabilities derived from each food category. Global per capita calorie and protein availabilities can also be computed. The malnourished population of each region depends on the population, per capita calorie requirements, and calorie availabilities. As the distribution becomes less equal (using the Eastern European region as a base), the malnutrition increases for a fixed calorie availability. World malnourished population is simply the sum across regions.

One of the linkages back to the economic model is the increase in agricultural value added relative to the base year. The model assumes a constant relationship between the value of gross production and value added. Gross production value is simply gross production times price, summed across agricultural categories.

Materials Submodel of WIM

The materials submodel of WIM is a partial economic equilibrium model and represents regional production, consumption, and pricing in three categories of metals: copper, aluminum, and iron. Demand responds to changes in income and prices. Primary production is based on development of production capacity over time, where new capacity growth rate responds to changing materials price. Primary production is supplemented by secondary production (recycling). Resources pose a potential constraint upon production, and recoverable resources vary with price levels. Prices change so as to minimize excess supply or demand. The overall structure is very much the same as that of the energy and agricultural submodels.

Demand. Materials demand responds in WIM primarily to income and price changes. As with both energy and agricultural demand, however, WIM does not rely on a simple income elasticity. The model has too long a time horizon and regions pass through too great a range of economic development levels to allow an assumption of constant income elasticity. Instead, in all three submodels the income elasticity (or an equivalent concept) is computed endogenously as a function of economic development.

Figure 3-21 shows the materials model. Like the other commodity or physical models it has supply, demand, and trade components. The bottom of the figure traces the computation of material demand. It proceeds in two stages. First, an income-based demand is calculated and then a price-adjusted demand is calculated. The income-based demand is a function of the value added in each of the four economic sectors and the basic demand per billion dollars of economic output in each sector. This income-based demand is modified by a computed demand adjustment coefficient which takes into account the differences in unit demand at different levels of income or development stages. The price-adjusted demand is a function of the basic demand, the changes in materials prices, and the elasticities of materials demand. Each material demand is calculated taking into account the change from the initial year of prices in all three materials.

Supply. Materials supply in WIM is divided into three categories: primary, recycled or secondary, and changes in governmental

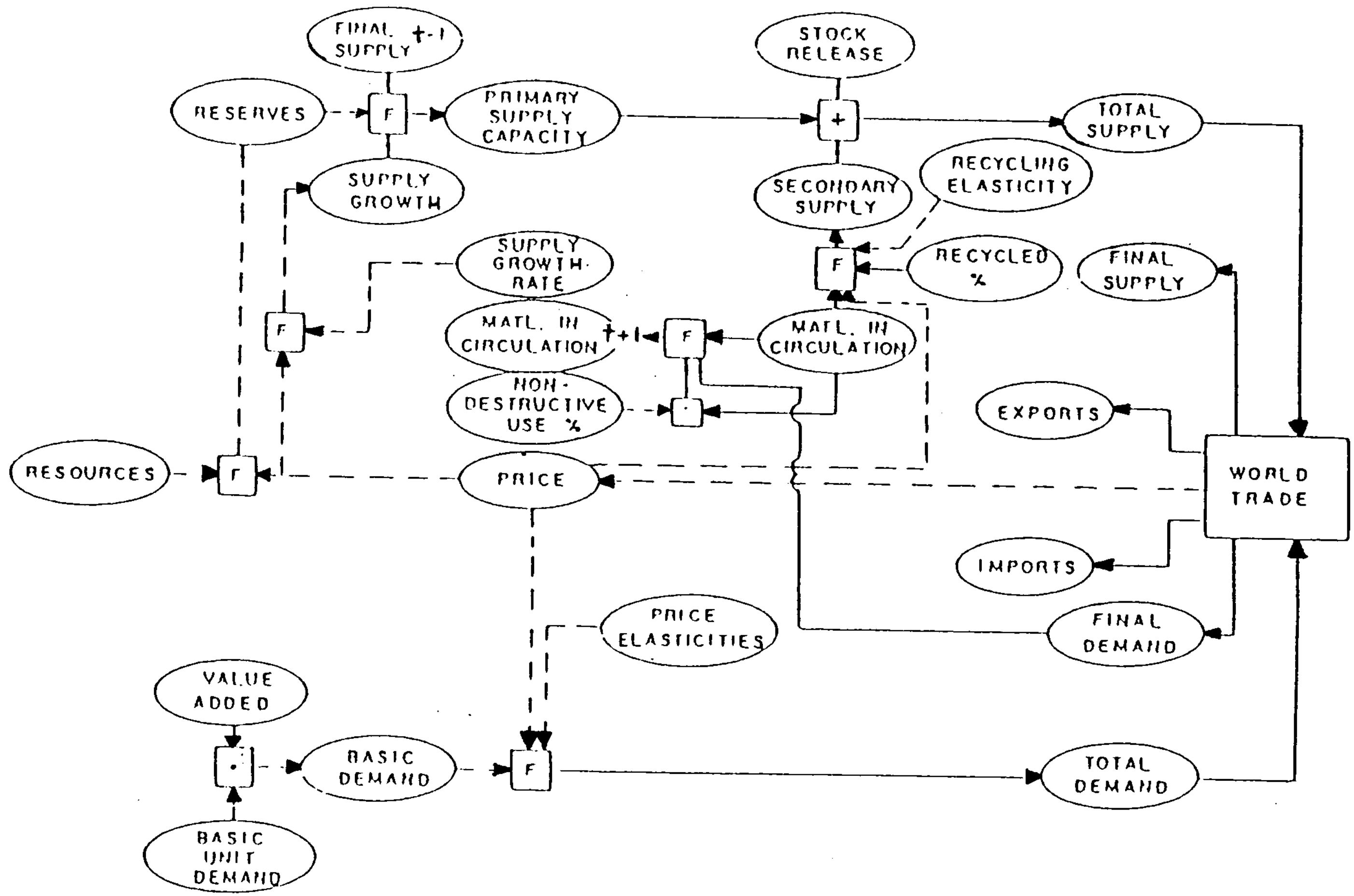

Figure 3-21. Materials submodel of the World Integrated Model.

Source: <u>World Modeling</u> (p. 138) by Barry B. Hughes, 1980, Lexington, Massachusetts D. C. Heath & Co.

stockpiles. Unlike the energy and agricultural submodels of WIM, the materials submodel does not explicitly represent the capital stock upon which production is based and the annual investment in it. It does, however, treat materials production capacity as a stock to be incremented by new capacity and decremented by depreciation, in an analogous fashion to energy or agricultural capital. Secondary production depends primarily on the amount of a material in general circulation and the portion which can be recycled in a given year.

The top of Figure 3-21 represents materials supply. The capacity for primary materials production is computed in two stages. First, a basic capacity is computed on a basis of last year's capacity, the lifetime of materials, and the change in materials production from year to year. The level of materials reserves can constrain production if the reserve to production ratio falls to a limit. Specifically, a dampening factor is computed as the ratio of the maximum allowable annual production and the actual capacity for production. The final production capacity level may or may not be constrained by the production dampening factor. Finally, actual capacity for primary production is the production capacity times a capacity utilization fraction.

The dynamics of primary supply involve an annual change to production capacity. One feature of the materials submodel not represented in the energy or agricultural submodels is a delay between capacity expansion and actual capacity formation. The basic change in materials production capacity is computed up to four years in advance of the actual change. The basic change in capacity four years from a given time step is a function of the basic capacity of production currently, the basic rate of materials capacity production growth, and the lifetime of materials production. Specifically, the change in production capacity four years hence depends upon the projected rate of production capacity minus the anticipated production capacity in the year prior to that in which the new capacity comes onstream. The basic change in material production capacity is modified to take into account the elasticity of supply with price and the price change from the base year of each of the three materials.

Recycled or secondary supply is a function of the material in circulation and a recycling fraction. This product is modified by an elasticity of recycling applied to the change in prices from the first year of all three materials. The material in circulation is updated each year as the previous value minus a portion of it which is used destructively plus the final demand for materials and minus that which is recycled. Finally, the total supply is the sum of primary production and recycled or secondary production and minus any exogenously specified change in the level of governmental materials stockpiles.

As in its energy submodel, WIM's materials submodel maintains variables for the ultimate resource base and for that fraction of it which constitutes known reserves. The ultimately recoverable resource base in materials is a function of the price of materials and thus of the economic feasibility of resource recovery. The annual discoveries of materials are a function of the ultimate global resource base and the fraction of that base which is in each region. Specifically, the discoveries are a fraction of the ultimate resource base minus cumulative production to date and minus already known or discovered resources. Cumulative production is updated in every time step by adding the final primary supply of materials. The known reserves of materials are updated in every time cycle as the previous value plus discoveries and minus final primary supply.

Supply/demand balance and prices. The WIM materials submodel is a partial economic equilibrium system like the energy and agricultural submodels. Demand and supply are both price responsive and prices change to maintain near balance over time in the dynamic equilibrium fashion. Excess demand is calculated after regional imbalances are at least partly eliminated in the world trade submodel.

The capacity for materials export is the difference between the regional supply and regional demand. Obviously, the capacity for export must be either positive or zero. Similarly, the capacity for imports is the difference between regional demand and regional supply, and again must be either positive or zero. Sums across regions provide the global export capacities and the global import capacity. Imports of materials and exports are computed in the trade submodel. Having those values, it is possible to determine the final demand for materials or actual consumption as the demand minus capacity to import plus actual imports. Similarly, the final supply or production of materials is the supply minus the capacity to export plus actual exports.

As in energy and agricultural submodels, WIM maintains a distinction between supply capacity and demand on the one hand, and production and consumption on the other. The latter two concepts must be equal on a global basis. The difference between the first two defines excess supply or demand. Materials prices, like those in agriculture and unlike those in energy, are computed globally rather than regionally. The price of materials is updated in each time cycle as a function of the prior price plus the product of excess supply and a price adjustment factor.

Machinery Submodel of WIM

The machinery submodel of WIM represents regional production and consumption of machinery in value terms. Demand consists of final demand and intersectoral demand, the former responding to total investment levels of the economy and the latter to machinery production levels, since the largest user of machinery is the machinery sector itself. Production levels change in response to excess supply or demand in the global system and assumptions about regional machinery production policies. Figure 3-22 represents the machinery submodel. This submodel, like the energy, agricultural, and materials submodels, has three primary components: demand, supply, and a process to achieve equilibrium.

Demand. Final demand for machinery derives exclusively from investment. Total investment demand is the sum of the original investment from the economic model and the portion of any external assistance directed to investment. Investment is primarily composed of

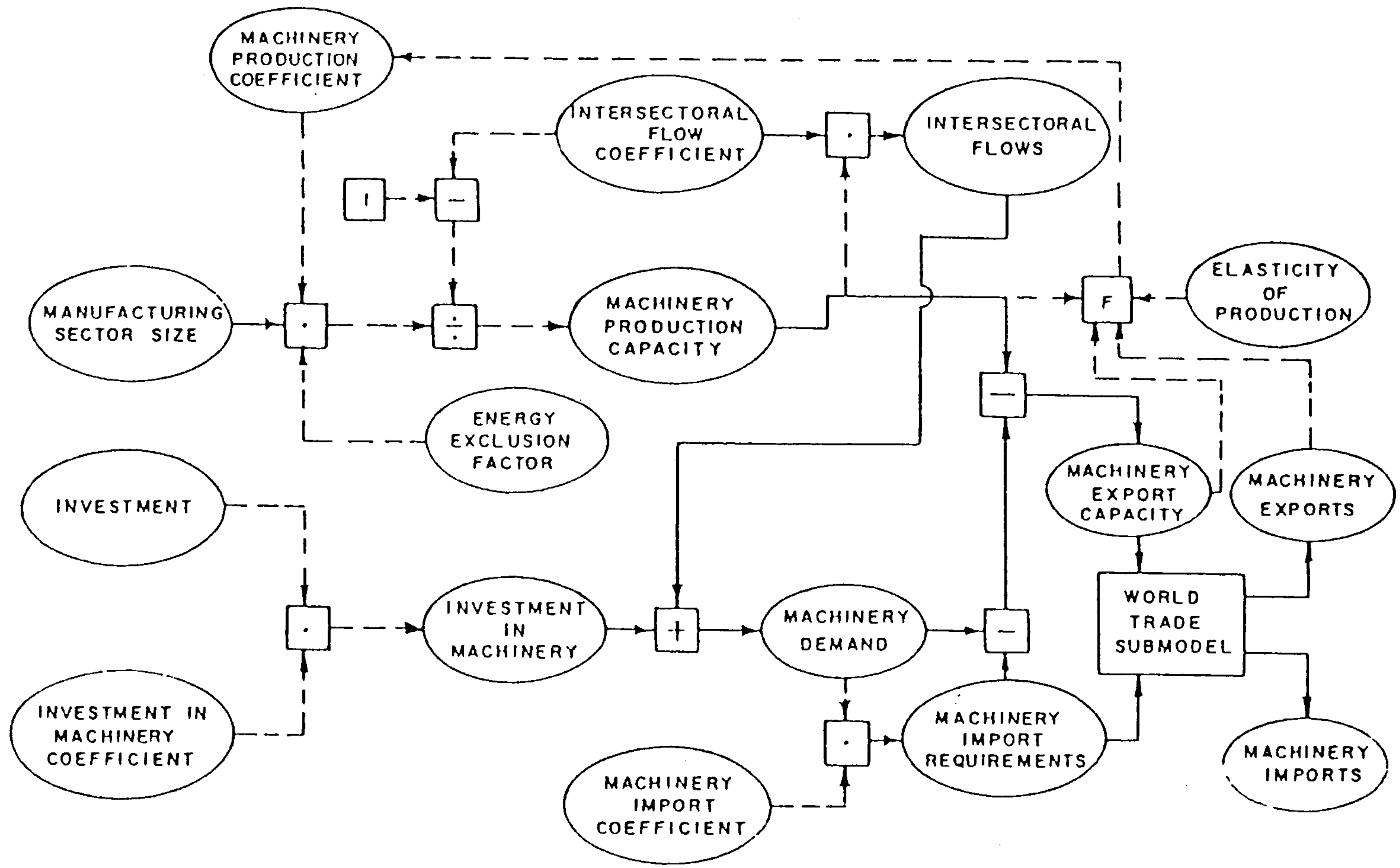

Figure 3-22. Machinery submodel of the World Integrated Model.

Source: World Modeling (p. 145) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

construction and machinery, with the model assuming machinery to be the limiting factor and to constitute a fraction of total investment. The total demand for machinery is a sum of final demand and intersectoral demand. Intersectoral flows themselves are a fraction of gross machinery production.

Supply. The supply portion of the machinery submodel is represented at the top of Figure 3-22. The machinery sector is a portion of the manufacturing sector. The machinery submodel relates changes in final demand deliveries of domestically produced machinery to changes in the value added of the manufacturing sector. The model first excludes from manufacturing value added the energy portion, through use of a multiplier, which more specifically excludes the portion of energy capital in manufacturing capital, assuming the capital ratio to be a good indicator of the value added ratios. Deliveries of domestic machinery to final demand is then computed from the residual manufacturing sector using a machinery production coefficient. The machinery production coefficient is computed the first time cycle from the difference between gross production of machinery and intersectoral flows, since that difference constitutes the domestic deliveries of machinery to final demand. Given machinery production for final demand and knowing the portion of gross production constituted by intersectoral flows, it is possible to compute gross production. An additional exogenous parameter can be used to increase machinery production at a rate faster or slower than the value added of the manufacturing sector.

Supply/demand balance. As with the other physical submodels, the supply/demand balance in machinery is accomplished in part through trade. Unlike the other submodels, this is done without explicit representation of prices. A fraction of total machinery demand constitutes import requirements. The fraction is computed endogenously on the first time step and depends on knowledge of initial imports. In addition, an exogenous factor can be used to increase or decrease the import dependence ratio. Export capacity for machinery is fully determined by production, demand, and import requirements. Actual imports and exports of machinery are computed in the trade model.

There are two primary differences between trade in machinery and trade in other commodities. First, machinery trade is gross rather than net. Second, machinery is not carried in physical terms, but rather in value. The latter makes computation of prices to clear the market less meaningful. Instead the model relies on adjustment of the machinery production coefficient using an elasticity of machinery production with the magnitude of excess capacity. The model targets a surplus of capacity of 10 percent.

Trade Submodel of WIM

The WIM trade submodel accepts import demands and export capacities from other WIM submodels and determines actual imports and exports. Most demands and capacities it receives are net and it predominantly uses a pooled trade approach. In addition, inadequate foreign exchange, as indicated by chronic and cumulative balance-of-payments deficits, constrains imports. The global import and export balance is maintained by an allocation mechanism relying primarily on trade volume and secondarily on relative regional prices.

The WIM trade submodel represents fifteen categories: five energy, five agriculture, three materials, machinery, and residual. When the sequence of model computations reaches the trade submodel, export capacities and import demands have been calculated for all categories except the residual. Coefficients to calculate the residual values as a percentage of GRP can be calculated the first year and used thereafter or specified exogenously. Adjustments can be made to export capacities or import demands as a result of exogenous policy decisions or because of foreign exchange shortages. Thereafter one of two algorithms (depending on whether trade in the category is gross or net) balances imports and exports globally.

Figure 3-23 shows the general trade submodel structure. That structure accepts the export capacities and import demands from the commodity models and computes actual exports and imports. It handles fifteen trade categories. Previous sections have described the procedures for determining import demands and export capacities for all trade categories except the residual category. In the residual category, they depend on the product of residual export and import coefficients and GRP, where the coefficients are computed in the first year and subsequently may be overridden by exogenous specification.

Two modifications can be made to the export capacities and import demands. First, a model user can optionally set export or import

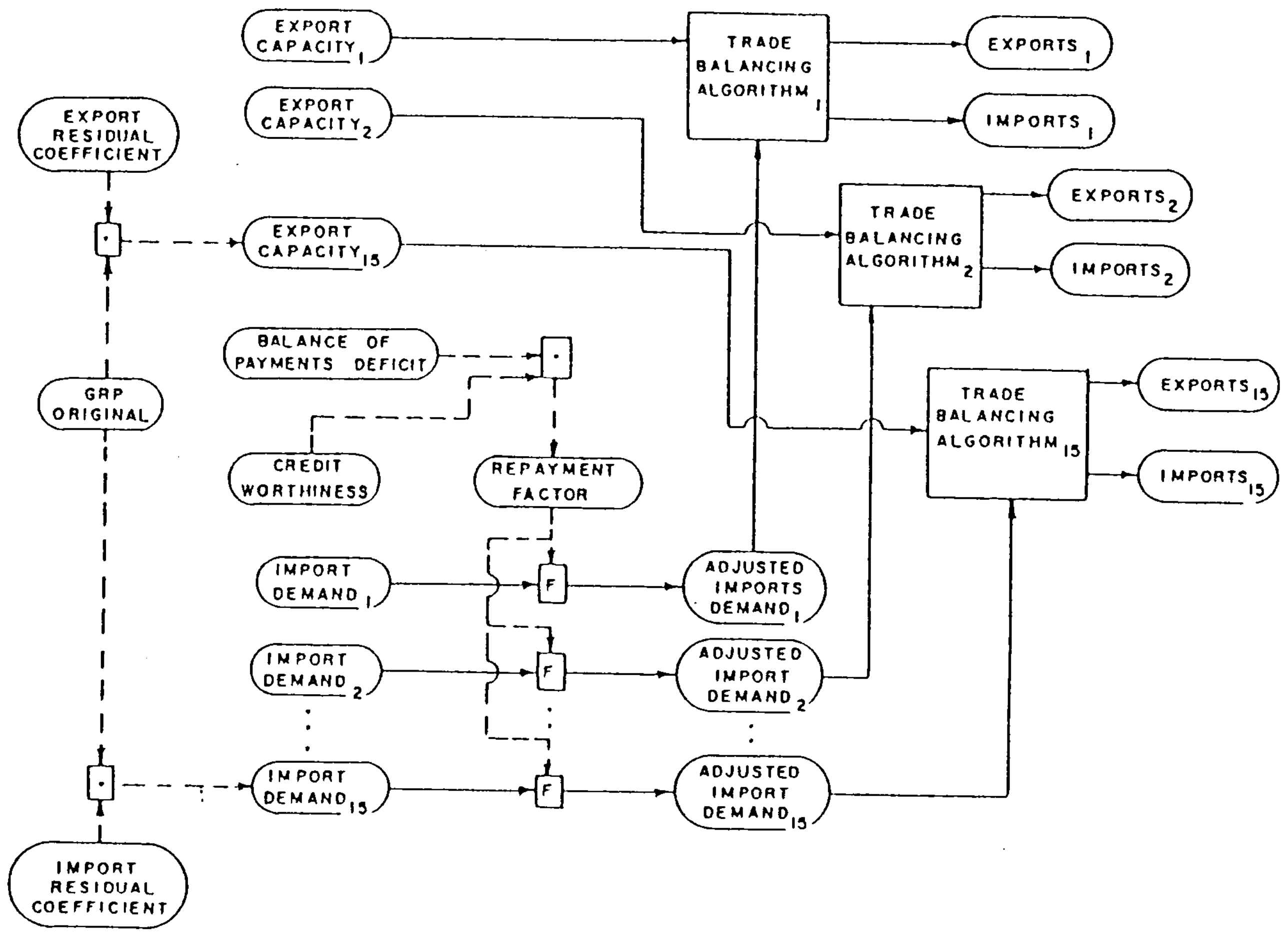

Figure 3-23. Trade submodel of the World Integrated Model.

Source: <u>World Modeling</u> (p. 160) by Barry B. Hughes, 1980, Lexington, Massachusetts D. C. Heath & Co.

limits. Second, when a region has a cumulative balance of payments deficit, it will find it difficult to finance continued imports at the domestic demand levels. An exogenously specified factor, representing credit worthiness of a region, will determine the portion of outstanding indebtedness which must be eliminated by reduced imports. The actual proportional reduction in each import category depends on the total dollar value of imports, that is, the volume times world price.

The world price for a commodity is simply that computed in the commodity submodel in most cases. When regional prices are computed as in energy, global prices are either those of a specific price giving region or a weighted sum of prices in all exporting regions at the discretion of the model user. In various versions of the model the reductions have depended on a weighing system so that on a policy basis the model user could sacrifice one category of import goods while protecting another category.

Trade balancing. After these two adjustments to export capacity and import demand, all that remains is to assure that global exports and global imports balance. Two different algorithms exist within WIM to obtain global balances, depending on whether trade is calculated on a net or gross basis. This section describes the net algorithm (which is used more often) while the next section describes the algorithm for gross trade balancing.

Figure 3-24 shows the procedure used in WIM to achieve global balance and to compute actual exports and imports for all traded

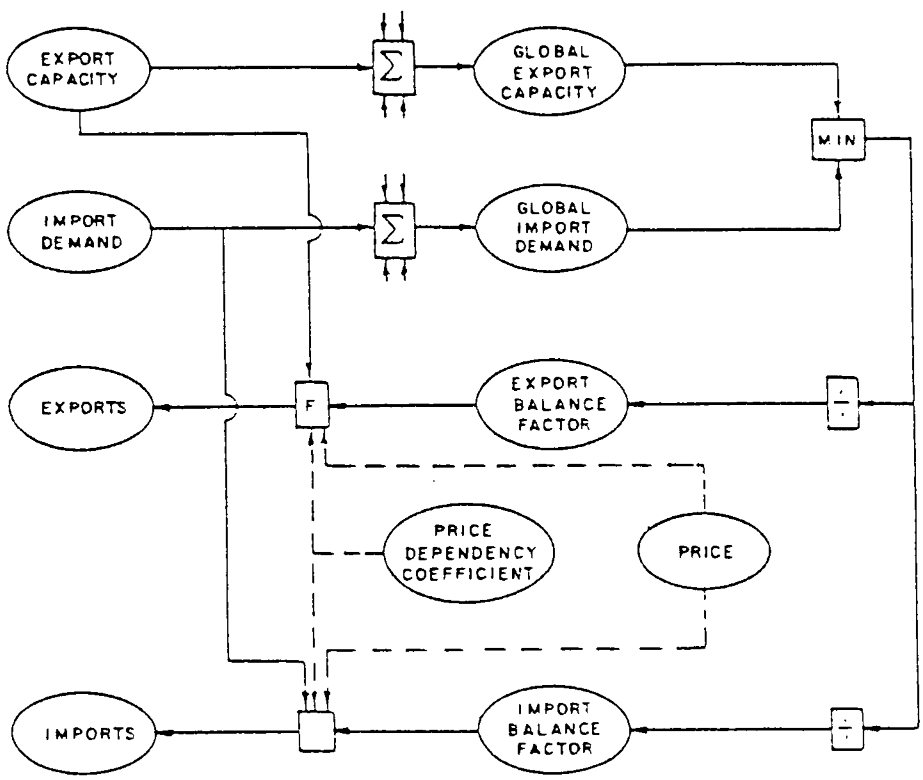

Figure 3-24. Trade balance algorithm in the World Integrated Model.

Source: World Modeling (p. 162) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

commodities except machinery, the procedure for which is described in the next section. The first step in this process is to sum global export capacity and global import demand. The smaller of these constitutes total world trade.

When a surplus of export capacity exists, exports must be reduced, and when a surplus of import demand exists, imports must be reduced. The algorithm contains two mechanisms for eliminating the surpluses. The first, used almost exclusively, relies upon proportional reduction. If export capacity is in surplus a supply or export reduction factor of less than one is calculated. If import demand is in surplus, a demand or import reduction factor is calculated. The second mechanism uses price to allocate the surpluses-lowest price exporters relative to the global price capture the market and highest price importers secure their supplies even when supplies are inadequate over all. The two mechanisms are combined by an exogenous coefficient which varies from one (entirely proportional allocation) to zero (entirely price allocation). The function in the second term involves an iterative process where the lowest price exporter or highest price importer captures as much of the yet unallocated market as desired until the supply and demand is balanced and both equal total world trade. Obviously, any surplus export capacity will be left for only the highest priced exporter and unfilled demand will be left with only the lowest priced importer. Actual model use has relied overwhelmingly, however, on the proportional allocation mechanism in the first term.

The discrepancy between export capacity and import demand on the one hand and actual exports and imports on the other is of considerable importance. It is from the differences that excess supply or demand is calculated for each commodity. Excess supply or demand in turn determines movement of price over time.

Machinery trade. Although the above procedure for balancing global exports and imports of a commodity can be used for all fifteen trade categories, a different one has been used for trade in machinery. More so than for other commodities represented in WIM, regions tend to both import and export machinery. Thus machinery trade has been treated in gross rather than net terms. Representation of gross trade allows use of a trade matrix rather than a pool. The matrix procedure is not necessarily superior to the pool approach, but it definitely is more complicated, because it requires alteration of the matrix terms each time cycle unless unreasonable rigidity is to be assumed in global trade over a long time period. The matrix adjustments allow regional shares in global exports and imports to adapt to changes in regional production and demand.

The first step in adjusting the trade matrix from the last time cycle is to compute a basic new matrix such that machinery import requirements are met. On the first time step the trade matrix is specified exogenously. The new matrix imposes export requirements upon all regions. The actual basic machinery export level will be equal to export requirements, as long as that does not exceed the export capacity determined in the machinery model.

In some regions there will be a surplus of export capacity above requirements, and there is a global surplus capacity. In other regions there is a surplus of export requirements above the capacity, and there is a global surplus requirement value. If the capacity surplus is smaller than the requirement surplus, the importers want all the machinery that the exporters can produce, so that exports are equal to capacity and imports will necessarily fall below requirements. If the capacity surplus is larger than the requirement surplus, the exporters must export more than the basic level computed to fill the requirement surplus, but need not export to capacity. Beyond the basic level they must export a portion of their capacity surplus which depends on the ratio between the requirement and capacity surpluses. In this case imports will meet import requirements.

It may not be possible to satisfy all import requirements, but it is unnecessary and undesirable to exceed import requirements. Thus yet another version of the trade matrix can be computed by eliminating any surplus imports. This alteration in the trade matrix makes it inconsistent with the hard constraint of the earlier determination of export levels. Thus the model iterates upon three equations until no region has any significant import surplus above requirements, a procedure which converges to the final trade matrix. The final matrix fully defines exports and imports.

Indicators. Only a few loose ends and indicators remain. Contracts for food trade were set aside before the computation of food import demand and export capacity. Now those contracts can be added back into food trade. Net trade flow and the dollar value of the flow can be computed for each region and commodity, using world prices. The total dollar volume of exports and imports can also be computed for each region. The total dollar value for a region of net food trade can also be computed. Finally, the cumulative balance-of-payments deficit or surplus can be updated. That involves the multiplication of the old value by an exogenously specified factor normally representing accumulation of interest or principal, but which can also represent default on or forgiveness of debt. To this adjusted carry-over debt or surplus is added exports minus imports and net nontrade financial transactions.

Other International Transactions of WIM

Nontrade financial transactions include foreign assistance grants and loans, international private investment, and tourism expenditures. WIM does not differentiate these. Total volumes of flows and either return flows or repayments are determined by parameters specified exogenously. Because of the policy orientation of WIM and the interest of WIM users in foreign aid and loans, the variable names and the structure emphasize aid.

Distinctions among categories of international transactions should be made clear. The first part of this chapter dealt specifically with trade in physical terms: coal and oil in billion barrels of oil equivalent, grain in million metric tons, and so forth. Corresponding to imbalances in the monetary values of these physical flows are "automatic" financial transactions, equal to the annual trade surplus or deficit. These may be governmental or private. The concern here is with additional and less automatic financial transactions, again both governmental and nongovernmental. These flows enter the overall balance of payments along with the automatic or trade-dependent flows and in turn will affect physical trade.

Figure 3-25 represents the nontrade financial transactions submodel. This submodel is used for a wide variety of scenario analyses and many of the variables are exogenous. The submodel contains two general mechanisms for transferring capital among regions. One is by making donations to a pool or by drawing on that pool, and the other is through fixed donations or fixed receipts.

There are three procedures for making contributions to the pool. The first is to make a contribution as a percentage of GRP. This corresponds, of course, to the target plans proposed in the international arena for transfer of 1 percent or 0.7 percent of the developed regions' GRP as aid. The second pool mechanism is to make a donation as a fraction of the pool, with the size of the pool determined by the recipient regions. The third mechanism for donating to the pool corresponds to putting as much funding into the pool as possible while maintaining a specified economic growth rate.

On the recipient side, the pool can be drawn upon on the basis of demand to achieve a specified percentage growth rate, or a fraction of

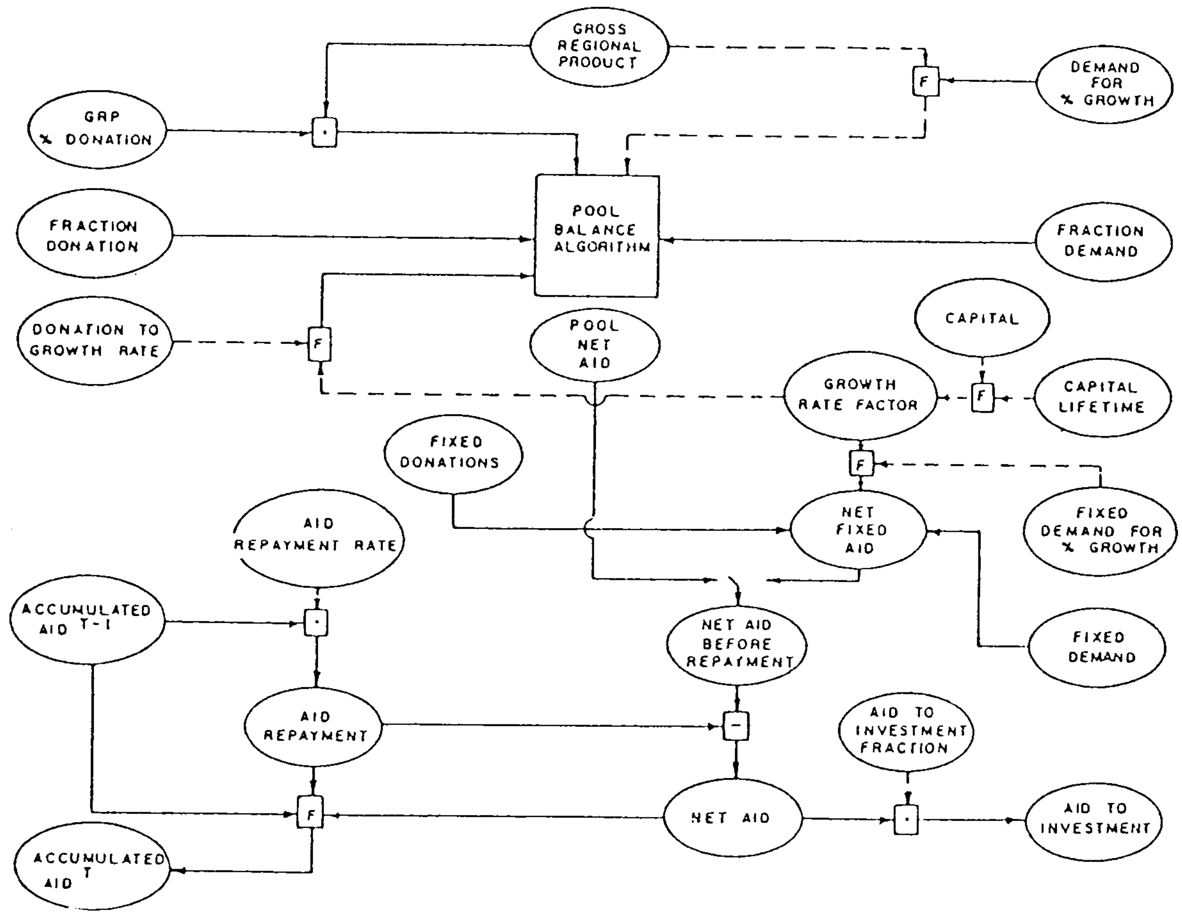

Figure 3-25. Financial submodel of the World Integrated Model.

Source: World Modeling (p. 168) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

the pool can be drawn. The pool balance algorithm sets actual pool size as the smaller of demand upon the pool or supply to it and eliminates surplus demand or donation levels.

Instead of the pool mechanism, it is possible to specify a given and fixed dollar value for international transfer or a fixed demand in order to achieve a specified percentage economic growth rate. The difference between the pooled and fixed procedures is that the latter intentionally do not require an international balance. Thus whereas the pool mechanism is used to represent normal monetary flows, the fixed procedures are used for special scenarios.

Net flow before repayment is either net pooled flow or net fixed flow. Repayment levels for regions of origin and recipients are the total flow accumulations over time divided by the aid repayment rate. Repayment levels increase or decrease net flow. A fraction of final net flow either goes to or is taken from investment and the rest adjusts consumption. Finally, accumulated flow at time t becomes the accumulated aid at time t - 1, plus additional net flow and minus the flow repayment level.

Results of WIM

An analysis of the results of the initial runs of the original model developed by Mesarovic and Pestel in the early 1970s differ very little from the results of subsequent runs of the updated WIM. The following discussion will concentrate on the results of the runs of the WIM. Specifically, five areas of the world's problematique are covered by the results. These include problems involving population growth, food supply and production, the world economic gap, energy resources, and environmental constraints. The models were run using four different scenarios. They are (1) standard, (2) continued aid, (3) delayed action, and (4) early action.

Population

The rate of the world population growth and the problems it causes was one of the main reasons the Club of Rome initiated efforts to analyze the world problematique. When the WIM was run in the 1970s, it concluded that all major regions except Africa have largely completed the transition to lower mortality rates and that most have begun the transition to lower fertility rates. In sum, the conclusion was that at that time the global population rate was beginning to fall. However, the model also revealed that the growth rates were not likely to fall more rapidly than they rose resulting in a predicted world population of eight billion by 2025.

Food Supply

Population growth places large demands on the food supply. WIM concentrates on the distributional relationship between population and food supply. It concluded that many of the areas with the greatest agricultural potential can least afford its development, and areas with the greatest food import needs can least afford those imports. Therefore, major political and economic issues stand between statements of theoretical production possibilities and realization of the potential.

South Asia was identified by both the original model and the WIM as the critical area with the most critical food supply problems. The more pessimistic scenarios called for three developments: accelerated progress in fertility reduction, increased emphasis on the development of local agriculture, and increased external assistance so as to provide additional food directly or the foreign exchange to buy it. The WIM also concluded that the instigation of just one of any of these three developments would not be enough to prevent starvation. The analyses also predicted that direct provision of food to South Asia in massive amounts would have the effect of discouraging the development of local production capacity and population programs. This would have the long-run effect of intensifying the problem.

WIM also calculated that at the time of the model run, 400-700 million people in the world were malnourished. The model further predicted under the most optimistic scenario that the number of malnourished would increase by 10-20 percent by the end of the century. The most negative scenario suggested a 75 percent increase in the number of malnourished persons in the world. The middle line between the two projections suggest that there will be an approximate 40 percent increase in the number of malnourished persons in the world.

Economic Gap

Another problem explored by the WIM is that of the economic gap between North and South in the globe. The ratio between per capita incomes in the richer and poorer countries of the world has remained nearly unchanged since World War II. However, during this same time the absolute gap between these countries has increased tremendously. The WIM predicted that the ratio could fall by 2025 but that any decrease was unlikely to be substantial.

WIM results also offer some insight into development strategies in less developed countries. The results of the model's runs suggests that an increased emphasis on the agricultural sector of such a country will accelerate long-term income growth. This conclusion is magnified by another prediction of a steady increase in relative food prices through the year 2025.

Energy Resources and Supply

The WIM has predicted that after 1990 there will be a significant rise in energy prices. This was based on the fact that in the short run, capital equipment, consumer energy using equipment, and the entire social and economic infrastructure is dependent on oil. This allows prices to rise significantly above costs of alternative energy.

WIM also tested for the possibility of the technology which would allow for the substitution of traditional liquid fossil fuels. WIM concluded that energy prices in the transition would have an impact of global economic growth. It also predicted that if energy were to become physically unavailable real damage would be done to economies.

The availability of three other metals was also analyzed by WIM. These metals are iron, cooper, and aluminum. The WIM predicted that within fifty years of the model's run none of the three metals would be significantly limited in supply as a result of resource constraints. However, the model also concluded that since ore grades are decreasing in quality with time, there will be high energy requirements per ton of finished metal. This would lead to higher energy prices possibly causing some material supply problems.

Environment

WIM does not perform a lot of calculation in the area of the environment. However, it does provide some interesting predictions in relation to atmospheric carbon dioxide levels. In 1975 industrial activities and deforestation had increased atmospheric carbon dioxide by about 12 percent of its preindustrial level. WIM predicted that this increase will reach 25 to 30 percent by 2000 and 50 to 65 percent by 2025.

Mesarovic and Pestel (1974), upon running the initial model, developed a list of conditions required for the solution of the major world crises and the strategies leading to that solution. They are as follows:

1. The current crises are not temporary, but rather reflect a persistent trend inherent in the historical pattern of development.
2. The solution of these crises can be developed only in a global context with full and explicit recognition of the emerging world and on a long-term basis. This would necessitate, among other changes, a new world economic order and a global resources allocation system.
3. The solutions cannot be achieved by traditional means confined to an isolated aspect of the world system, such as economics. What is really needed is nothing short of a complete integration of all strata in our hierarchical view of world development--that is, a simultaneous consideration of all aspects of mankind's evolution from individual values and attitudes to ecological and environmental conditions.

4. It is possible to resolve these crises through cooperation rather than confrontation; indeed, in most instances cooperation is equally beneficial to all participants. The greatest obstacles to cooperation are the short-term gains that might be obtained through confrontation. Even if these gains are short-lived and demonstrably lead to long-term losses, there is always a pressure to go after these gains. (pp. 143-144)

These conditions can best be achieved in an atmosphere of organic growth. In fact the model builders feel that organic growth is the "natural" way to control the undifferentiated growth going on in the world. They go on to qualify the immediate first steps needed on a social or individual basis in order for a master plan for organic growth to be developed. The steps are as follows (Mesarovic and Pestel, 1974):

1. The realization that counterproductivity will be the ultimate consequence of any action confined solely to short-term considerations. This must be accepted as a basic premise in all decision-making processes. Long-term assessment ought to become standard procedure in the consideration of fundamental decisions regarding developmental issues. Only in such a way can organizations--businesses, governments, or international units--actively contribute in consciously influencing the emerging world system. Otherwise they might very well become nothing more than passive passengers on a voyage charted by outside forces.
2. The futility of narrow nationalism must be appreciated and taken as an axiom in the decision-making framework. Global issues can be solved only by global concerted action.
3. Development of a practical international framework in which the cooperation essential for the emergence of a new mankind on an organic growth path will become a matter of necessity rather than being left to good will and preference. Balance between constituent parts of the world system is needed to achieve that end; among other implications this suggests the need for stronger regional arrangements and accelerated development in certain parts of the world. Such developments are in the best interest of all regions, i.e., the entire globe.
4. Realization of the overriding importance of the long-term global development crises and willingness to place this

> highest on the agenda of the issues to be dealt with explicitly by national governments and international organizations. Precisely because the symptoms of these global crises might become fully visible only toward the end of the century, the time to act is now; when the symptoms become clear the remedy will no longer be possible. Future history will not focus on personality and social classes, as has been characteristic of history in the past but on the use of resources and survival of the human species. The time to affect that history is now. (pp. 144-146)

The modelers realized that the above conditions require more than just a change in societal structure. Therefore, they developed a list of individual values and attitudes they felt were necessary for the new global ethic to survive. Those values and attitudes are as follows (Mesarovic and Pestel, 1974):

1. A world consciousness must be developed through which every individual realizes his role as a member of the world community. Famine in Tropical Africa should be considered as relevant and as disturbing to a citizen of Germany as famine in Bavaria. It must become part of the consciousness of every individual that the basic unit of human cooperation and hence survival is moving from the national to the global level.
2. A new ethic in the use of material resources must be developed which will result in a style of life compatible with the oncoming age of scarcity. This will require a new technology of production based on minimal use of resources and longevity of products rather than on processes based on maximal throughput. One should be proud of saving and conserving rather than of spending and discarding.
3. An attitude toward nature must be developed based on harmony rather than conquest. Only in this way can man apply in practice what is already accepted in theory--that is, that man is an integral part of nature.
4. If the human species is to survive, man must develop a sense of identification with future generations and be ready to trade benefits to the next generations for the benefits to himself. If each generation aims at maximum good for itself, Homo Sapiens is as good as doomed. (p. 147)

In sum, the results of both the initial Mesarovic and Pestel model and the updated WIM urge for humankind to initiate changes to lead to a more stable world. Specifically, they call for a strategy for change which can only evolve in the spirit of truly global cooperation and guided by a rational master plan for long-term organic growth. In the modelers' own words (Mesarovic and Pestel, 1974): "All our computer simulations have shown quite clearly that this is the only sensible and feasible approach to avoid major regional and ultimately global catastrophe, and that the time that can be wasted before developing such a global world system is running out" (p. 157).

CHAPTER 4

THE UNITED NATIONS WORLD MODEL

Methodology of Input-Output Models

The United Nations' world model is based on input-output methodology. Wassily Leontief published the first input-output table for the American economy in the 1930s. The world view held by input-output analysis has three basic elements. They are as follows (Council on Environmental Quality and the Department of State, 1980):

1. We cannot predict the future of the world economy. However, we can rule out of our expectations future scenarios that are internally inconsistent and thus impossible.
2. To rule out internally inconsistent expectations we need to construct a model that guarantees internal consistency. This we can do by visualizing the world as a system of interdependent processes in which

   > each process, be it the manufacture of steel, the education of youth or the running of a family household, generates certain output and absorbs a specific combination of input. Direct interdependence between two processes arises whenever the output of the one becomes an input of the other: Coal, the output of the coal mining industry, is an input of the electric power generating sector. The chemical industry uses coal not only directly as a raw material but also indirectly in the form of electrical power. A network of such length complicates the system of elements which depend upon each other directly, indirectly, or both. (Leontief, 1977, p. 823)
3. If it is the world we want to model, we can enhance the above visualization by dividing the world into regions and representing, separately, flows within a region and flows between regions. (p. 649)

This world view is developed in an immense and complicated mathematical structure. It is composed of a vast system of simultaneous linear equations. The system is solved by making the number of equations equal to the number of unknowns. This is accomplished through the use of exogenously specified values for key variables. For projection purposes, the exogenous variables along with some of the equations' coefficients are projected forward and the whole system is solved again. The model allows the user to decide which variables are to be exogenous or endogenous in each model run.

The Transactions Table

The basis of the input-output model is the transactions table (see Figure 4-1). This table shows how the output of each industry is distributed among other industries and sectors of the economy. Simultaneously, it shows the inputs to each industry from other industries and sectors. An input-output table can include any number of input-output industries depending on the degree of aggregation desired.

One of the major advantages of this model is the degree of aggregation it allows. As a general rule, input-output modelers allow for the maximum amount of disaggregation when developing the basic transactions table. However, there are cases where it is more beneficial to consolidate sectors. Such a case is when the model is to concentrate on a few number of particular sectors.

In the transactions table each row shows the output sold by each industry or sector along the left-hand side of the table to each industry or sector across the top of the table. Each column shows the purchases made by each industry or sector along the top of the table from

From \ To		Purchasing sectors	Local final demand: Households	Private investment	Government	Exports	Total gross output
		$1 \ldots j \ldots n$					
Producing sectors	1	$X_{11} \ldots X_{1j} \ldots X_{1n}$	C_1	I_1	G_1	E_1	X_1
		. . .	.	.	.	.	.
		(I)		(II)			
	.	. . .	.	.	.	.	.
	.	. . .	.	.	.	.	.
	i	$X_{i1} \ldots X_{ij} \ldots X_{in}$	C_i	I_i	G_i	E_i	X_i
	.	. . .	.	.	.	.	.
	.	. . .	.	.	.	.	.
	.	. . .	.	.	.	.	.
	n	$X_{n1} \ldots X_{nj} \ldots X_{nn}$	C_n	I_n	G_n	E_n	X_n
Labour		$L_1 \ldots L_j \ldots L_n$	L_C	L_I	L_G	L_E	L
		(III)		(IV)			
Other value added		$V_1 \ldots V_j \ldots V_n$	V_C	V_I	V_G	V_E	V
Imports		$M_1 \ldots M_j \ldots M_n$	M_C	M_I	M_G	–	M
Total gross outlay		$X_1 \ldots X_j \ldots X_n$	C	I	G	E	X

Figure 4-1. Simplified input-output transactions table.

Source: Input-Output and Regional Economics (p. 19) by Harry W. Richardson, 1972, New York: John Wiley & Sons.

the industries and sectors along the left-hand side of the table. For example, element X_{ij} in quadrant I in the transactions table represents the amount of output produced by industry i and bought by industry j. The basic rules for reading the transactions table are (Miernyk, 1965):

1. To find the amount of purchases from one industry by another, locate the purchasing industry at the top of the table, then read down the column until you come to the producing industry.
2. To find the amount of sales from one industry to another, locate the selling industry along the left side of the table, then read across the row until you come to the buying industry. (p. 11)

The roman numerals illustrated in Figure 4-1 represent the four major quadrants in the transactions table. Each quadrant represents a submatrix to the input-output matrix. The various quadrants have specific functions. These are discussed below.

Interindustry flow submatrix. Quadrant I is the interindustry flow submatrix. This portion of the model is produced endogenously. In Figure 4-1 the rows are represented by the letter i and the columns are represented by the letter j. The section is also known as the processing sector. This section contains the industries producing goods and services.

Final demand submatrix. This sector of the model is shown in Figure 4-1 as quadrant II. This is the autonomous part of the input-output matrix. Changes that occur in this sector are carried on throughout the rest of the table. Within this sector are the local final demand and external final demand (exports) variables. Represented in the columns of quadrant II of Figure 4-1 are the demand factors of households, public investment, the government, and exports. The intersection of Row 5 and column 1 in quadrant II is represented by C_i which is the amount of household consumption of the production of industry i found on the left-hand side of the table.

Primary input submatrix. Quadrant III represents the primary input submatrix of the input-output transactions table. This sector is also known as the Value Added submatrix and the Payments submatrix. The rows in the sector are read all the way across the transactions table. The variables found here are representative of the inputs not produced within the interindustry submatrix (quadrant I). Included in this sector are external imports (represented by the letter M in Figure 4-1). The other rows of this section show the factor payments coming down from the various purchasing sectors to the local population. For example, the variable L_j found in row 1, column 2 of quadrant III is representative of the amount of payments made to local workers by industry j. The variable V_j represents all other local payments to factors of production such as land, rent, and profits. The import row of quadrant III is also representative of income leakage from the region in the form of all inputs from outside the region.

Accounting submatrix. Quadrant IV makes up the accounting submatrix. This matrix combines the factors from quadrants II and III. For example, variable L_C found in row 1, column 1 of quadrant IV represents the number of people working in households while the variable

L_G, just two columns to the right, represents the dollar value expended by the government for its employees. This sector is known as the accounting sector because it is used to make the variables total from quadrants II and III.

While the previous discussion outlined the four quadrants, one section of the transactions table remains to be explained. The last row and column of the table represent the total gross outlay and total gross output of the region respectively. In the transactions table, total gross outlay must equal total gross output.

Total gross outlay shows the total value of inputs to each of the industries and sectors in each column at the top of the table. For example, the variable X_j found in the last row and second column of the table represents the total gross outlay of sector j. This industry j spends part of its income on intermediate expenses and the rest on value added expenses. The intermediate expenses are found in quadrant I and consist of the sum of all the amounts spent by industry j to purchase the goods of all industries i. These values are found in column 2 of the transactions table and can be mathematically expressed as

$$\sum_{i=1}^{n} X_{ij} .$$

The value added expenses are found in column 2 of quadrant III. The variables L_j and V_j represent the amount spent by industry j on labor and other value added factors of the region. The variable M_j represents the expenses paid by industry j to factors imported to the region. This portion of money is lost to the local region. The value added expenses can be illustrated mathematically as

$$L_j + V_j + M_j \ .$$

Therefore, the equation for total gross outlay for industry j is

$$X_j = \sum_{i=1}^{n} X_{ij} + L_j + V_j + M_j \ .$$

Total gross output shows the total value of output of each of the industries and sectors along the left-hand side of the table. In the transactions table, the total gross outlay of each industry in the processing sector must equal the total gross outputs of that industry. Therefore, in the transactions table in Figure 4-1, the first nine values in the Total Gross Output column are identical to the first nine values in the Total Gross Outlay row. While this does not hold true for the rest of the rows and columns in the table, the total amount of total gross outlays and the total amount of total gross outputs must equal. In other words, the last row and last column of the transactions table must add to the same figure. In the table in Figure 4-1 that grand total is represented by the variable X.

In order for the last row and last column to sum to the same amount, the total of the rows in quadrants III and IV must equal the total of the columns of quadrants II and IV. Even though the individual totals of the individual rows and columns differ, altogether they must sum to the same amount. For example in Figure 4-1, the value of C + I + G + E must be equal to the value of L + V + M. This must be true even though the individual values of C, I, G, E, L, V, and M may all be very different.

Coefficients

Once the basic transactions table has been constructed, a table of direct input or technical coefficients can be developed from it. A technical coefficient is the amount of input required from each industry to produce one dollar's worth of the output of a given industry. Technical coefficients are calculated only for the industries in the processing sector. The value of the coefficient may be expressed in either monetary or physical terms.

In order to examine the derivation of technical coefficients, the transactions table in Figure 4-1 has been reduced to that of Figure 4-2. This input-output matrix has only three sectors plus variables Y and V which represent final demand and value added, respectively. In this table, when the sum of the values in row i from the three industries is subtracted from the ith industries' gross outlay the result is equal to the final demand of the ith industry. For example, using sector 1:

$$X_1 - (X_{11} + X_{12} + X_{13}) = Y_1 \; .$$

If the amount of industry 1's output purchased by each of the purchasing industries is a stable function of the latter's output, then the above equation may be rewritten as:

From \ To	1	2	3	Final demand	Gross output
1	X_{11}	X_{12}	X_{13}	Y_1	X_1
2	X_{21}	X_{22}	X_{23}	Y_2	X_2
3	X_{31}	X_{32}	X_{33}	Y_3	X_3
V	V_1	V_2	V_3	—	V
Gross outlay	X_1	X_2	X_3	Y	X

Figure 4-2. Skeletal input-output table.

Source: Input-Output and Regional Economics (p. 27) by Harry W. Richardson, 1972, New York: John Wiley & Sons. Copyright 1972 by Harry W. Richardson.

$$X_1 - a_{11}X_1 - a_{12}X_2 - a_{13}X_3 = Y_1 ,$$

where

$$a_{11} = X_{11}/X_1 \; ; \; a_{12} = X_{12}/X_2 \; ; \; a_{13} = X_{13}/X_3 \; .$$

Each technical or direct input coefficient (a) represents the direct requirement of the output of any sector i per unit of output of any other purchasing sector j.

When these direct input coefficients remain constant over time, they provide a means of linking final demand to gross output. These coefficients make it possible to analyze the effects of specified changes in final demand on gross output. These effects take place in several rounds. First there is a direct effect on gross output, but there are also indirect effects of additional deliveries of these inputs on all industries in the economy. In order to analyze these indirect effects on gross outlay the input-output table is converted to a matrix. This matrix has an equation which represents a set of equations, with one equation like the previous

$$X_1 - a_{11}X_1 - a_{12}X_2 - a_{13}X_3 = Y_1$$

equation for each sector. The resulting matrix equation is

$$X - AX = Y$$

where X and Y are column vectors of gross output and final demand respectively, and A is an n x n matrix of direct input coefficients

(a_{ij}). With the use of the identity matrix the equation can be rewritten as

$$(I - A)X = Y \ .$$

This in turn can be rewritten as

$$\begin{bmatrix} 1-a_{11} & -a_{12} & \cdot & \cdot & \cdot & -a_{1n} \\ -a_{21} & 1-a_{22} & \cdot & \cdot & \cdot & -a_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ -a_{n1} & -a_{n2} & \cdot & \cdot & \cdot & 1-a_{nn} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_n \end{bmatrix} = \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_n \end{bmatrix}$$

If the Y vector has at least one nonzero value then $(I - A)$ has an inverse. This inverse matrix can be used to express output as a function of final demand. This is expressed as

$$X = (I - A)^{-1}Y \ ,$$

where $(I - A)^{-1}$ is the inverse matrix.

In order to examine the indirect effects on output due to a change in final demand, let $B = (I - A)^{-1}$. In this case,

$$B = \begin{bmatrix} b_{11} & \cdot & \cdot & \cdot & b_{1j} & \cdot & \cdot & \cdot & b_{1n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ b_{i1} & \cdot & \cdot & \cdot & b_{ij} & \cdot & \cdot & \cdot & b_{in} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ b_{n1} & \cdot & \cdot & \cdot & b_{nj} & \cdot & \cdot & \cdot & b_{nn} \end{bmatrix}$$

and so $X = BY$. Within the inverse matrix B are the interdependency coefficients (b_{ij}). The coefficient b_{ij} represents the direct and indirect requirements of industry i per unit of final demand for the output of industry j. Therefore,

$$X_i = b_{i1}Y_1 + b_{i2}Y_2 \dots + b_{ii}Y_i + b_{ij}Y_j + \dots + b_{in}Y_n .$$

The inverse matrix B can be multiplied by any size and composition of final demand in order to calculate the level of gross output for each industry.

<u>Multipliers</u>

One of the advantages of the input-output model is the ability to measure the total impact on employment, income, and output from any change in investment. This effect is examined through the use of a multiplier. J. M. Keynes developed the basic multiplier to illustrate that if a certain amount of income was injected into the economy, consumer spending would rise but by an amount less than the income injection. The amount of added income spent by consumers becomes someone else's "new" income. The latter then spend some of their additional income and the spending cycle continues for many more rounds. Keynes determined that if the marginal propensity to consume could be measured then so could the income multiplier. Keynes was dealing with aggregate multipliers. It is often desirable, however, to examine impacts on separate sectors of the economy. Input-output models allow for this type of disaggregated multiplier. The model user is also given the opportunity to examine the effects of changes in expenditure on output, income or employment. This is accomplished by the use of different types of multipliers for each (output, income, and employment).

Interregional Input-Output Models

The UN world model is actually constructed with fifteen separate regional models all interacting together. A basic understanding of the functioning of interregional input-output models is necessary before the specific structure of the UN model is explained. This section will provide the reader with the necessary information on interregional modeling.

In interregional input-output modeling, each region involved is treated in equal detail. Each region has its own interindustry matrix. In addition, interindustry flows between each region are represented by a set of interregional matrices, with one matrix for each pair of regions. With this structure, each economic activity can be identified by industrial group and by location. The aggregate interregional technical coefficient matrix has $(nz)^2$ separate cells, where n is equal to the number of industries and z is the number of regions in the model. Each region has a n x n matrix for its own industrial structure and z - 1 other n x n matrices representing the interindustry interregional trade relationships.

In interregional input-output models, any industry i in one region could be identical to another industry i in any other region. However, the interregional model treats them as separate industries due to the fact that they are located in different regions. As a result, the interregional modeling structure treats interregional interindustry coefficients on the same basis as local interindustry coefficients. They are both considered standard input coefficients. Therefore, any change in final demand directly calls for a proportional change in each of the inputs. This holds true not only for each local industry but also for each industry input from the other regions. This makes the measurement of the technical coefficients between regions crucial to the use of the interregional model. In order to derive these coefficients, measurements have to be made of interregional flows by region of origin and destination and by industry of source and purchasing sector.

Figure 4-3 illustrates the "ideal" interregional input-output transactions table. It contains two regions--East and West. Each region contains n number of industries. The X_{ij} in the $E \rightarrow E$ section of the figure represents the amount of output of industry i produced in the

From \ To		East (E)	West (W)	Exports out of country	Total gross output
		1 . . . n FD_1 FD_2	1 . . . n FD_1 FD_2		
East (E)	1 . . . n VA_1 VA_2	I E→E X_{ij}	II E→W X_{ij}		
West (W)	1 . . . n VA_1 VA_2	III W→E X_{ij}	IV W→W X_{ij}		
Imports from outside country					
Total gross outlay					

Figure 4-3. Ideal interregional input-output transactions table.

Source: Dr. Henry W. Herzog. Handout from lecture in Methods of Regional Analysis. 1985, The University of Tennessee, Knoxville.

East region and sold to industry j which is also located the East region. In the section immediately to the right of the E → E section is the E → W section. The X_{ij} here represents the amount of the output of industry i which is in the East region sold to industry j located in the West region. The same principles can be applied to the last two sections of the model.

Reading across the interregional transactions table is much the same as the procedure for reading a single region input-output table. For example, given any producing industry in quadrant I, the amount of its output can be traced to purchasing industries in quadrant I and quadrant II. Some portion of the output may also be sold as exports out of the area covered by the transactions table.

Structure of the UN Model

The purpose of the UN model is to display various possible interrelationships, as the world economy evolves over future decades, between environmental and other economic policies. The model was originally constructed specifically for the study of development in relation to environmental problems. The principal environmental policies considered are those concerning pollution, constraints on the extraction of mineral resources and the production of food. However, as the following description will illustrate, the model is basically a general-purpose economic model and so is applicable to the analysis of the evolution of the world economy from various points of view. In order to reasonably predict the world economy, the model's time horizon was set to depict the world economy of 1970 and compare it to projections for 1980, 1990, and 2000.

Level of Aggregation of the UN Model

Geographically, the model has divided the world into fifteen regions. Specifically, the regions include four developed market regions (North America, Western Europe (high-income), Japan, and Oceania); six developing market regions (Latin America (medium-income), Latin America (low-income), the Middle East and African Oil Countries, Asia (low-income), Africa (arid), and Africa (tropical); one region including the countries of Asia with centrally planned economies; and two medium-income regions (Western Europe (medium-income), and Southern Africa).

Basically, these geographic groupings reflect a reasonable degree of homogeneity in the economic variables that characterize those nations combined in a single regional unit. One of the primary factors used to categorize these areas was the level of economic development as measured by per capita income levels and the share of manufacturing activity in total GDP. The other factors leading to the regional classification were determined by the original modeling team as those factors which were important to the United Nations' research. This led to the oil-exporting countries being grouped together and the division of African nations into those receiving less than ten inches of rainfall annually and those receiving more. In general, the regional groupings follow continental boundaries for the reasons of data collection and to be able to compare model projections with data produced by various international agencies. The obvious exception to this generality is the grouping of the oil-producing countries of the Middle East and Africa.

Each of these fifteen regions is described as a separate regional model, which when solved simultaneously, represent the whole world system. Structurally, each of the fifteen models are identical. Each regional model contains 175 equations and 229 variables which describe the interactions between the production and consumption of various goods and services. Each region has 45 sectors of economic activity. In agriculture, four specific subsectors are analyzed. These four subsectors are livestock products, grains, high-protein crops, and roots. In analyzing mineral resources, special attention is given to copper, bauxite, nickel, zinc, lead iron ore, petroleum, natural gas and coal. Manufacturing activities are divided into 22 sectors, such as food processing, primary metals, textiles, fertilizer, and various types of machinery and equipment. There is also separate treatment of utilities and construction, trade and services, transportation and communication. Lastly, the model describes emissions of eight types of major pollutants and five types of pollution-abatement activities.

Although each of the fifteen regions is treated separately, they are all connected through a complex set of linkages consisting of the exports and imports of 40 classes of goods and services, capital flows, aid transfers, and foreign interest payments. With these linkages the fifteen submodels are solved simultaneously to simulate the world system. The model also allows a detailed analysis of prospective changes in technology, cost of production and relative prices.

Structure of the Regional Submodel

Leontief and the original modeling team (1977), developed a block of equations belonging to a single regional model. This blocking is set up in schematic form and is found in Plate 2 (in pocket). All the letters and symbols found within the matrix represent the coefficients of variables that enter into the linear equations described by each row. The variables themselves are listed at the heads of the columns. For example, the symbol, @, found at the intersection of row 50 and column 81 in Plate 2, represents the set of technical coefficients that represent inputs of traded goods (XT) per unit of output of nontraded goods (XNT). In reality, the variable XT represents the class of nineteen traded goods while the variable XNT represents the class of six nontraded goods; and the symbol @ represents the coefficients of a 19x6 portion of the regional input-output table. So although it is very large, Plate 2 is a highly summarized example of the structure of the regional submodel. A key to the symbols representing the coefficients used in Plate 2 is found in Appendix D.

The equations represented by a particular row in Plate 2 can be identified by the name of the leading variable that is found at the left of the table. The variable is what the equation defines or explains in terms of some other variables. All variables in the table are abbreviated. The full names of the variables found on the left-hand side of the table can be found in the key to rows in Appendix E. All other variables are listed in the key to columns in Appendix F. All variables are listed in full in Appendix G.

The variables are measured in various ways. Some are measured in physical units while others are in monetary (dollar) units. For the base year 1970, all values are in 1970 United States prices. For the years 1980, 1990, and 2000 the monetary values are expressed either in current-year relative dollar prices or in constant 1970 dollars. Dollar figures representing the values of outputs, inputs, exports, imports or stocks of particular goods in 1970 prices can be interpreted as measurements of their physical amounts. Certain variables in the model are known as "slack" variables and are extra variables added to some of the equations. There are several reasons for using slack variables. If a slack variable is treated as one of the unknowns, the final result will be the same as would have been obtained if the equation in question were simply eliminated from the system; except that the magnitude of the slacks as it came out in the numerical solution will indicate by how much the relationship into which it was inserted would have to change in order to be compatible with the rest of the system.

A general computer program for processing a large system that contains equations which are kept in force for some solutions and have to be suppressed for some others can be greatly simplified by the use of slacks. If the value of the slack entered into an equation is set to be zero, that equation is kept in force. To switch it out one simply has to treat the slack as one of the unknown variables. When treated as an exogenously determined variable, a slack can also be conveniently employed to introduce a change in the shape of the equation in which it enters--for instance, an upward or a downward shift in a curve.

An equation can be reconstructed from each row by multiplying each coefficient entered along the row with the variable identified by the symbol located above it in the top row of the table, and then setting the sum or the terms so formed to equal zero. For example, the equation corresponding to the first row of coefficients reads:

$$-M_1 * GDP + CONS + INVS + GOV + EXPRT - IMPRT$$
$$+ P_1 * URBAN + P_2 * ABATE + INVCH = 0$$

where $M_1 = 1 + M_2$, M_2 = the percentage of GNP spent on pollution abatement in 1970, P_1 = per capita cost of urban service, and P_2 = abatement costs per unit of pollution abated. This equation can be transformed into an explicit definition of gross domestic product, as used in the model:

$$GDP = \frac{1}{1 + M_2}\begin{pmatrix} CONS + INVS + GOV + EXPRT - IMPRT \\ + P_1 * URBAN + P_2 * ABATE + INVCH \end{pmatrix}$$

Each equation, or group of equations, in Plate 2 can be transformed to explain the variables, or groups of variables, that give their names to the rows of the table. The equations contained in the system are tabulated in algebraic form in Appendix H.

Macroeconomic Balances of the Regional Submodel

The balances for the macroeconomic variables are described in equations 1 through 9. These equations show how the main elements of the regional accounts, such as regional GDP, gross investment, and employment, are related to other activities in the system and to each other. The multiplication of GDP with M_1 in the first term of equation 1 compensates for the cost of abatement, P_2 * ABATE, that is already included in the conventional measure of the GDP for the base year 1970. Regional accounts for future years are also expressed in 1970 prices, so only an increase in the proportion of pollution abated (M_2) is registered as an increase in GDP. In order to take account of the abatement expenditures in GDP, any increment in the rate of abatement over that actually realized in 1970 (i.e., M_2) is multiplied by the 1970 "prices" (i.e., unit cost) of abatement and summed into the Gross Domestic Product. Even though inventory is treated as analogous to investment, it is recorded as a distinct element of GDP in order to keep in accord with standard conventions. Personal consumption of specific goods is treated as a function of income per capita. The coefficients found in columns 2 and 9 of Plate 2 are terms in the linear approximations of the consumption functions of the region. The coefficients, C, of column 2 measure the amounts of specific agricultural products (AGS), metal and energy resources (RSS) and industrial products (XT and XNT) consumed per dollar of additional total expenditure. The coefficients in column 9 represent the population term in the linear consumption functions. For any given level of consumption expenditure, these coefficients show how the amounts of the various specific products will increase or decrease with an increase in population. Housing is treated as household investment. The capital coefficients, K, in columns 2 and 9 represent the consumption expenditure and income terms that determine the level of housing required at any given spending and population level. Expenditures on the collection of household liquid and solid wastes and water supply are specified as "urban amenities." Their level in any given region depends on the size of the urban, rather than the overall population.

The second equation determines DSAVE which is the positive or negative excess of desired private saving over the actual volume of investment. It is a slack variable. Government saving is set equal to government investment. However, the potential supply of private savings is determined as a percentage of GDP plus net inflows of foreign capital and foreign aid. For a single region, unless explicitly set equal to zero, DSAVE may have a positive or negative value. Due to the internal logic of the system, the DSAVE must be matched by a shortfall or an excess of actual, as compared to the normal level of consumption, a positive or negative element in aid and capital flows, or some combination of the two.

Each year's investment is the sum of four elements: equipment, plant, land development, and irrigation investment. Further details of the treatment of investment are found in rows 75, 76, and 87 through 91 of Plate 2. In any given year, the stocks of plant and equipment capital required to support current production are determined by capital coefficients (K). Investment required over a ten year period must cover depreciation as well as the difference between current requirements and the stock of capital at the beginning of the decade. Equation 91 keeps track of the requirements of arable land, while the levels of investment in land development and irrigation are set exogenously. Columns 97 though 101 show the industrial composition of the four different types of domestic investment--that is, the proportional allocation of a dollar's worth of equipment investment among the sectors producing machinery, electrical machinery and the like, and the industrial composition of inventory change.

Labor coefficients are found in row 8, representing employment per unit of output in the various industrial, household, and government sectors. Labor coefficients are specified for agriculture only for the developed countries. Therefore, total regional employment includes the entire employed labor force in the developed regions but excludes the agricultural labor force in the lower-income regions.

Input-Output Balances of the Regional Submodel

The input-output balances of the modeling system are found in rows 11 through 69 of Plate 2. Rows 50 through 68 illustrate the total requirements of nineteen internationally traded manufactures per unit of output of the corresponding domestic producing sectors. Included in the purchasers of these inputs are household consumers, government and investment, as well as other industrial sectors. Separate rows represent specific products measured in physical units, such as specific agricultural products (AGS) and specific resource products (RSS).

Residual agriculture (AGR--which is all agricultural production with the exception of animal and milk products, cereals, high-protein crops and root crops), residual resources (RSR--which is all minerals other than the six metals and three energy resources specifically enumerated) and food and resource processing margins (AGM and RSM) are also shown separately, but they are measured n 1970 value units.

Pollution and Abatement in the Regional Submodel

Equations 13 through 31 are the pollution balances of the system. The equations for setting the levels of abatement activity are found in rows 11 through 15. Rows 16 through 23 contain the emissions coefficients, which measure the quantities (e.g. metric tons of biological oxygen demand, suspended solids, particulate matter) emitted per unit of output of each economic activity. Emissions coefficients are specified for urban households as well as for all agricultural and industrial processes. Net total emissions (EMA) measure the volume of each pollutant that is emitted minus the amount treated by the abatement sector (ABATE). However, abatement activities in turn generate pollution and so can eliminate only a fraction of the pollution they treat. So, particulate abatement eliminates more than 99 percent of the emissions treated, while primary water treatment eliminates only 80 percent of the suspended solids and none of the nitrogen pollution in the water it treats. The coefficients in rows 24 through 31 measure residual pollution after treatment by the abatement processes. This pollution (EMNA) is not abatable in the sense that it is the proportion of treated emissions remaining after treatment. The variable EMTOT is the sum, for each pollutant, of untreated emissions and residual emissions after the abatement processes have been applied. So, EMTOT measures the total volume of emissions that remains to render whatever damage or discomfort can be attributed to pollution.

<u>Investment Balances in the Regional Submodel</u>

The required stocks of plant and equipment (SPLT, SEQP) are computed by multiplying sectoral production levels by their respective capital coefficients found in rows 84 and 99. For the year 1970, investment in plant and equipment (found in equations 75 and 76) is determined by multiplying the required stocks by the sum of the growth rate and the estimated rates of replacement of the stocks in question. For later years, replacement investment is still considered a fixed percentage of capital stock in place, while investment for expansion is computed as the difference between required capital (SPLT, SEQP) and that in place ten years earlier (HPLT, HEQP).

Equations 78 through 86 total the consumption of mineral resources over successive decades. Information on cumulative resource extraction provides a basis for projecting the future costs of extraction: as the more accessible reserves of a resource in a given region becomes exhausted, the next layer which involves higher extraction costs begins to be exploited.

International Transactions in the Regional Submodel

The remaining equations in Plate 2 determine the imports and exports of the various types of goods and services discussed above. This system does not identify the region of origin of any region's imports, nor the destination of any region's exports. Instead, every exporter sells to a "pool" of traded goods, from which importing regions draw their imports. Equations 92 and 131 deal with imports. In general, imports are specified as a given ratio of imports to domestic output. The import/output ratios, A, are derived from a set of import coefficients, each one of which represents the proportion of total domestic consumption of a particular commodity that is satisfied by imports in a particular region. Imports of services, primarily foreign travel, are tied directly to GDP, and imports of transportation to total imports. So, every region draws an amount from the world pool of specific products in accordance with its domestic consumption and its import coefficients.

In terms of the export pool, each region is assigned a given share of the total pool for each commodity. Equations 132 through 172 state that a region's exports of each kind of output is a given proportion, B, of the total world pool. World pools are represented by the pool variables, PAGS, PAGR, PRSS and so on.

In comparing a table that describes the composition of the exports of a region with one that lists the imports of that region, the modelers found that in most instances the region appeared to be an importer and exporter of the same goods. This reflects the process of classification by which different kinds of goods are grouped together. Also, within the model, exports and imports of the countries combined in a single region are aggregated, making the flow of goods traded between any two countries not netted but rater listed both as exports and imports of that region. Therefore, coefficients and export shares generally represent gross rather than net trade. An exception is found in the case of metal and energy resources, which are treated on a net basis. Therefore, a region can be both an importer and an exporter of metal refining services, but it can only appear as either a net importer or a net exporter of metal content. Resource refining margins traded by any region are assumed to be equal to their 1970 volumes plus a specified proportion of imports or exports of specific resource products in excess of the base year. Agricultural margin trade is computed by multiplying the trade in each of the specific agricultural products by a region-specific processing margin percentage. Interregional financial transfers are separated into capital flows, which change a region's international indebtedness and thus also generate interest payments and aid payments, which are treated as pure grants.

The balance of payments, BAL, is the sum total of deficits or surpluses of the following three external accounts--the difference between the value of exports and imports of the region, (EXPRT-IMPRT); the difference between the capital inflows and the capital outflows of the regions, (ECAP-MCAP); the difference between the foreign aid obtained and supplied by the region, (EAID-MAID)--and the net foreign income payments received or made by the region. In other words, the balance of payments, BAL, by definition, is the net compensating flow of foreign short-term credit. It represents a gap between the long-term financial intakes and outlays of a given region.

The cumulative level of indebtedness which constitutes the base for the determination of annual interest payments is computed so as to include not only cumulative ordinary capital flows but also cumulative annual positive or negative balances of payments, as defined above.

Results of the UN World Model

The United Nations World Model has been used as a policy testing mechanism for organizations commissioning the use of the model. Some of the uses of the model have been to: (1) test economic and environmental consequences of the growth targets established by the International Development Strategy; (2) investigate for the U.S. Department of Commerce the consequences of energy conservation on global economic development; and (3) examine a few scenarios that the modelers themselves felt were useful and meaningful. The results of these three tests follow.

The work done for the United Nations revolves around eight policy scenarios. As prescribed by the International Development Strategy, most of these are based on exogenously given forecasts of population growth and growth of income per capita. The three population and income growth alternatives examined here are shown in Table 4-1. The standard forecast, represented in the table as UN/B is the case with medium population growth and high gross domestic product per capita growth in developing regions and moderate growth in developed

Table 4-1. Alternative Assumptions Concerning Income Targets and Future Population Growth.

	Population Growth		Per Capita GDP Targets	
	Developed Regions	Developing Regions	Developed Regions	Developing Regions
UN/B	medium	medium	high	high
UN/A-1	low	low	low	high
UN/A-2	high	high	low	high

Source: Global 2000 Report to the President (p. 653) by Council on Environmental Quality and the Department of State, 1980, Washington, D.C. U.S. Government Printing Office.

regions. Further tests were conducted by altering this standard forecast by changing assumptions. For example, more optimistic estimates of resource endowments were assumed, as well as increased foreign aid, constraints on balance-of-payment deficits, and faster agricultural investment in the low-income Asian countries. In one final scenario, investment instead of being driven by targeted GDP growth, was presumed to follow past trends, and GDP growth was generated endogenously according to several constraints: apparently realistic balance of payments, the labor available, and the monies available for investment after consumption had spent its share. The constraints used varied from region to region.

In the process of solving the model with the above policy scenarios, the modelers found that the minimum targets set for growth by the International Development Strategy, if implemented, would barely suffice to keep the gap between rich and poor nations from growing, much less to narrow the gap. Accordingly, the growth rate per capita income in less developed countries (LDCs) was adjusted upward in such a way that the income gap between LDCs and industrialized countries would just about halve its proportionate size by the year 2000. Consistent with the objective of leveling out income levels, growth rates across the board were adjusted so as to be inversely related to present income per capita. The richer regions were assumed to grow slowly, the poorer regions to grow most rapidly.

In the work conducted for the U.S. Department of Commerce, the modelers compared a business-as-usual constrained growth run with one in which all regions of the world adopt the highest reasonable curtailment of fossil fuel consumption over the next 20 years. Their conservation maximum was adopted from the most extreme of the energy conservation scenarios prepared by the Cavendish Laboratories of Cambridge University for the Worlds Energy Conference in October of 1977. They assumed that energy conservation would be accomplished by substituting labor and capital for energy.

The tests described above produced less than optimistic prospects for the LDCs in general. For such countries to meet the targeted growth rates, investment ratios of unprecedented magnitude would have to be maintained, and consumption for private use kept at very low levels. For example, if target growth rates were kept up in the year 2000, none of the developing regions would have a level of personal consumption in excess of 63 percent of income, and none would have a level of private investment of less than 20 percent. It was also found that in order to meet food requirements in a standard scenario, agricultural production in the year 2000 would have to be increased to about four times present figures. Higher rates of increase were called for in many places. In low-income Latin America and low-income Asia, it was found that agricultural output would have to increase by more than 500 percent; in arid and tropical Africa and centrally planned Asia, increases of 100 to 500 percent were indicated; in the Middle East, the output showed that a 950 percent increase in agricultural output would be required to keep economic growth patterns on target. In currently high-income regions, most of the indicated agricultural growth rates were below 200 percent (Leontief et al., 1977).

The results regarding minerals were more optimistic. In general, it was found that mineral resource limitations would not prove to be a binding constraint on economic growth by the year 2000. With the exception of lead and zinc, the model did not show the world running out of any minerals by 2000.

In regard to pollution, Leontief's analysis of the model (Leontief et al., 1977, p. 7) concludes that "although pollution is a great problem for humanity, it is a technologically manageable problem" and that the economic cost of keeping pollution within manageable limits is not unbearable. Model output implied that if fairly stringent abatement standards were to be applied to all the pollutants now regulated in the United States, abatement costs would come to about 1.4-1.9 percent of gross product. Under less stringent standards--in the model it was assumed that less stringent standards would be applied in countries with lower income per capita than the U.S.--the total cost of abatement activities would come to about 0.5-0.9 percent of gross product.

The energy conservation tests conducted by the Department of Commerce resulted in several tendencies for the world. Some of these tendencies are discussed below. In the developed regions, which were modeled as having labor-constrained growth rates, energy conservation's greatest effect was to reduce balance-of-payment deficits. In the LDCs, where GDP growth was constrained by balance-of-payment deficits, energy conservation, in reducing balance-of-payment deficits, lessened the main constraint to economic growth and thereby resulted in increased GDP growth as well. In all regions, the capital requirements for energy conservation caused the energy conservation scenario to require more savings, and thus less consumption. The required change in savings rates was large enough to imply the need for an appreciable change in the distribution of money between savings and consumption--an increase in savings of about 17 to 23 percent (Leontief et al., 1977).

In the modeler's own test runs, they constructed scenarios to compare the economic consequences for LDCs of adopting standard patterns of development instead of a pollution-intensive export strategy. The purpose of the test was to ascertain whether LDCs would be lessening their prospects for economic growth if they avoided becoming specialized hosts for higher pollution generating industries. From these tests, the modelers concluded (Council on Environmental Quality and the Department of State, 1980) that:

> the pollution-intensive approach is found to be more expensive in terms of capital, and requires more input. This approach would also imply sizeable shifts in the output mix of the developing economy and might create nonnegligible environmental repercussions. . . . In sum, several economic criteria mitigate in favor of the conventional and against the pollution-intensive strategy--provided, and this is quite important--that a choice exists at all. (p. 655)

Other conclusions resulting from the model study centered on consequences of accelerated development in the less developed countries. The modelers listed (Leontief et al., 1977) the most important among these to be: (1) accelerated development would probably require faster growth of heavy industry than of other industrial sectors; (2) high income-elasticities of demand for imports would likely create severe balance-of-payment problems for LDCs under accelerated development strategies; and (3)

> to ensure accelerated development two general conditions are necessary: first, far-reaching internal changes of a social, political and institutional character in the developing countries, and second, significant changes in the world economic order. Accelerated development leading to a substantial reduction of the income gap between the developing and the developed countries can only be achieved through a combination of both these conditions. (p. 11)

CHAPTER 5

ASSESSMENT OF THE MODEL RESULTS

Making an assessment of the results of the output of the models examined in the previous chapters is a difficult task for many reasons. First, the physical amount of output from any large simulation model is virtually infinite. Secondly, there are several levels on which a project can produce "results." Three types of results come from each of the three models examined in this study. These are enumerated by John Richardson (1978) as those which are:

1. Specifically derived from the model,
2. Consistent with and supported by the model results, but not specifically derived from them, and
3. More general conclusions of the authors resulting from the experience of developing and using the model over a long period of time. (p. 175)

All three of the models downplay the results of the first type. In fact, they all provide a "disclaimer" of sorts to that effect. They argue that the models should only be viewed as planning and decision-making tools. The real "results" are the product of a particular decision-maker, concerned with a specific set of problems, interacting with the model. It is the third type of result that is preferred by the modeling teams. These are the least formal of the three types of results and in the long run may prove to be the most valuable.

For reasons of uniformity for the purpose of comparison, the results of the three models most basic runs will be analyzed. In particular, for World3 the "reference run" will be examined. This is the run of the model where the historical trends from the period of 1900-1970 are projected into the year 2100. In effect, this run is an extrapolation of the present conditions without any changes. For the World Integrated Model, the "standard scenario" will be analyzed. Like the reference run of World3 this path describes the world situation if the historical patterns of development were to continue. The United Nations model is a little harder to fit into a basic or standard run category for comparison purposes. This is due to the nature of the purpose for the development of the model. However, the model does have a basic scenario run called "X" which will be examined as its conservative run which meets the standards set by the International Development Strategy.

Results of the Reference Run of World3

The modeling team for World3 first performed a historical run with the model which depicted the world system for the period 1900-1970. The reference run, which will be examined here, was executed by projecting the trends found from the historical run into the year 2100. The reference run is depicted in Figure 5-1.

Figure 5-1 is written in DYNAMO graphical form. It is important to know how to read a DYNAMO graph in order to understand Figure 5-1 and the other graphs found in this section. The first line to the left of the graph lists the symbols used for plotting each variable. For example, NRFR is the variable name for nonrenewable resource fraction remaining, in the DYNAMO program, and the symbol used for

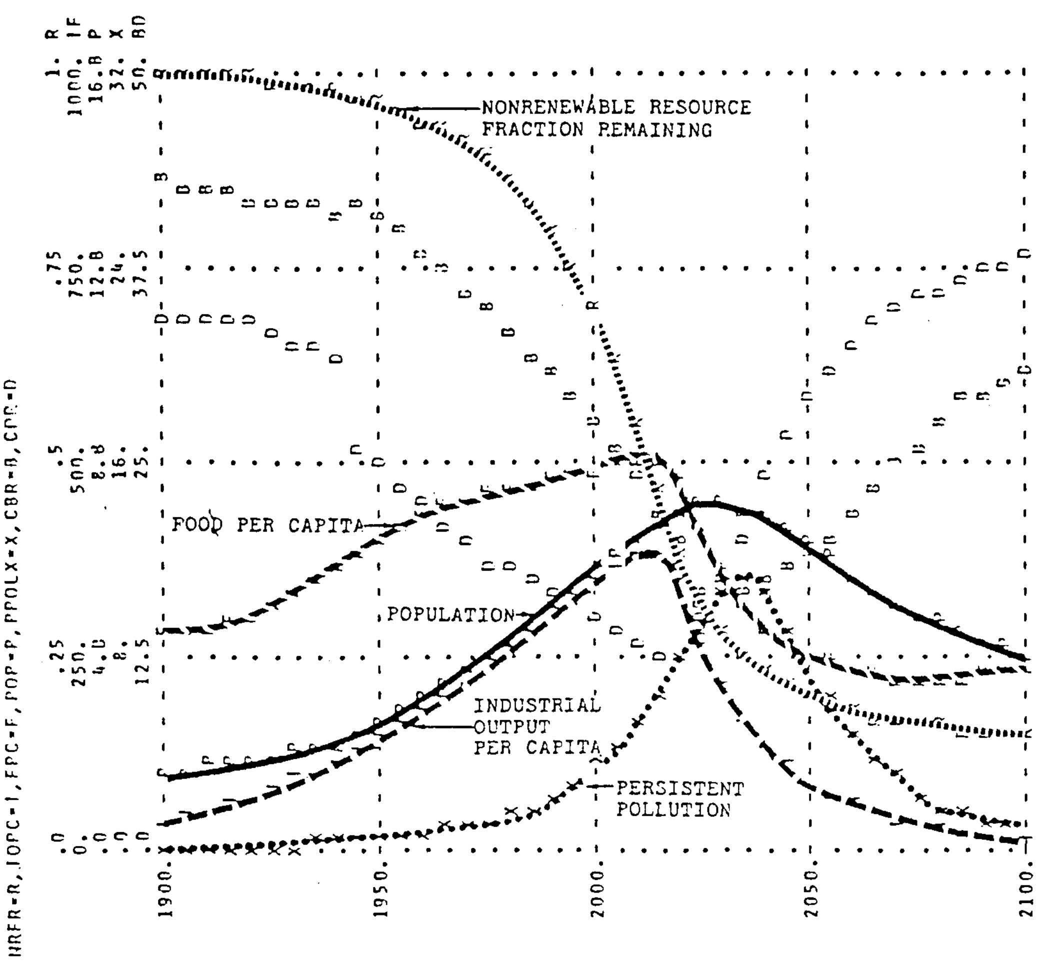

Figure 5-1. World3 reference run.

Source: Dynamics of Growth in a Finite World (p. 501) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

plotting NRFR is R. (See Appendix A for a full listing of the variables and their abbreviations). The remaining lines to the left of the graph give the scales for the plotted variables. The scales are divided into four equal parts by the compiler. Scientific notation is used and the power of ten, employed as a scaling factor, is represented either with a standard exponential designation, for example 5 E+10, or with an alphabetic character (see Table 5-1). For example, the scale for POP, plotted as P in Figure 5-1, has an upper value of 16.B, which is 16 x 10 units. In Figure 5-1, both industrial output per capita, IOPC (plot symbol I), and FPC, food per capita (plot symbol F), are plotted on the same scale. Likewise, crude birth rate, CBR, (plot symbol B) and crude death rate, CDR (plot symbol D), are plotted on the same scale. Time is plotted along the horizontal axis of the graph. The compiler attaches a "date" to the scale at every tenth plot period.

In the reference run of World3 (Figure 5-1), the global population, after reaching the 1970 level of 3.6 billion people, continues to grow to a level of six billion in the year 2000 and peaks at about seven billion in the year 2030. After that time the crude death rate (CDR) exceeds the crude birth rate (CBR), so that the population (POP) declines. Food per capita (FPC) rises steadily throughout the twentieth century to more than 500 vegetable-equivalent kilograms per person-year, but it declines sharply after 2015. Industrial output per capita (IOPC) reaches a maximum value of 375 dollars per person-year in 2015. The index of persistent pollution PPOLX reaches a peak of eleven times the 1970 level of pollution in the year 2035. The overall behavior of Figure 5-1

Table 5-1. Scaling Letters Used in DYNAMO Notation.

Letter	Multiply Plotted Value by	Letter	Multiply Plotted Value by
A	10^{-3}	N	10^{30}
B	10^{9}	P	10^{24}
C	10^{27}	Q	10^{15}
D	10^{33}	R	10^{12}
E	10^{-6}	S	10^{21}
F	10^{-9}	T	10^{3}
G	10^{-12}	U	10^{-24}
H	10^{-15}	V	10^{18}
J	10^{-18}	W	10^{-27}
K	$<10^{-30}$ (off scale)	X	1
L	10^{-21}	Y	10^{-30}
M	10^{6}	Z	$>10^{33}$ (off scale)

Source: Dynamics of Growth in a Finite World (p. 604) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

ais best defined in the terms of Forrester and Meadows as overshoot and decline. Population and capital grow past their sustainable physical limits and then return to a preindustrial level of development. Growth is halted in this run through the effects of nonrenewable resource depletion.

The reference run can be better understood by examining the behavior of several additional model variables from the same computer reference run (see Figure 5-2 and Figure 5-3). As the nonrenewable resource fraction remaining (NRFR) drops below 0.5 in the year 2015, the fraction of capital that must be allocated to obtaining those resources (FCAOR) begins to rise above its minimum level of 0.05 (see Figure 5-2). Therefore, industrial capital must be diverted from the production of industrial output toward obtaining the resources necessary to sustain that output. When investment in industrial capital no longer exceeds depreciation, the industrial capital base declines, reducing industrial output (IO) and industrial output per capita (IOPC).

As industrial output (IO) declines, the total agricultural investment (TAI) is also forced to decrease (see Figure 5-2), even though the agriculture sector tries to compensate for the reduction in food per capita (FPC) by increasing the fraction of industrial output allocated to agriculture (FIOAA) after the year 2025. The decrease in total agricultural investment (TAI) causes the agricultural inputs per hectare (AIPH) to decline after a short delay. Due to the fact that the model's agricultural sector is highly capital intensive, a decrease in agricultural inputs per hectare (AIPH) immediately depresses land yield (LY), which

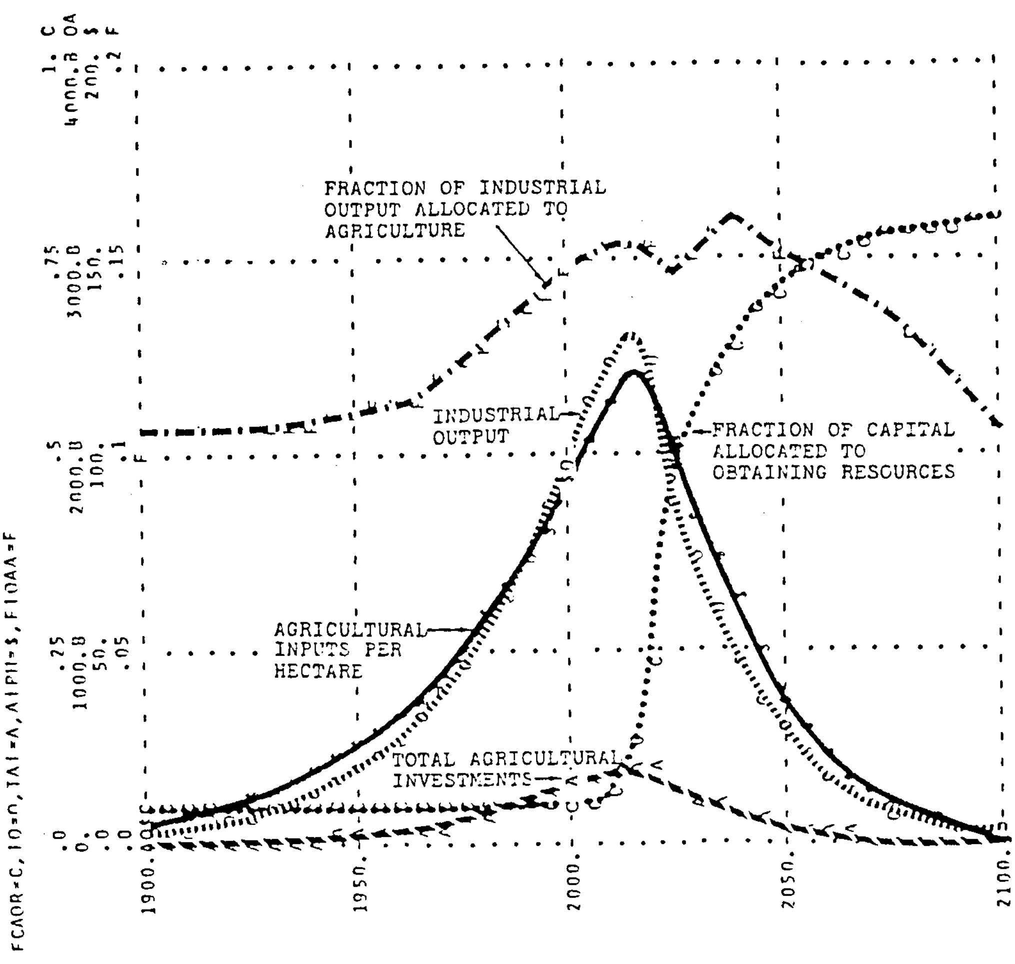

Figure 5-2. Capital sector variables from the reference run.

Source: Dynamics of Growth in a Finite World (p. 502) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

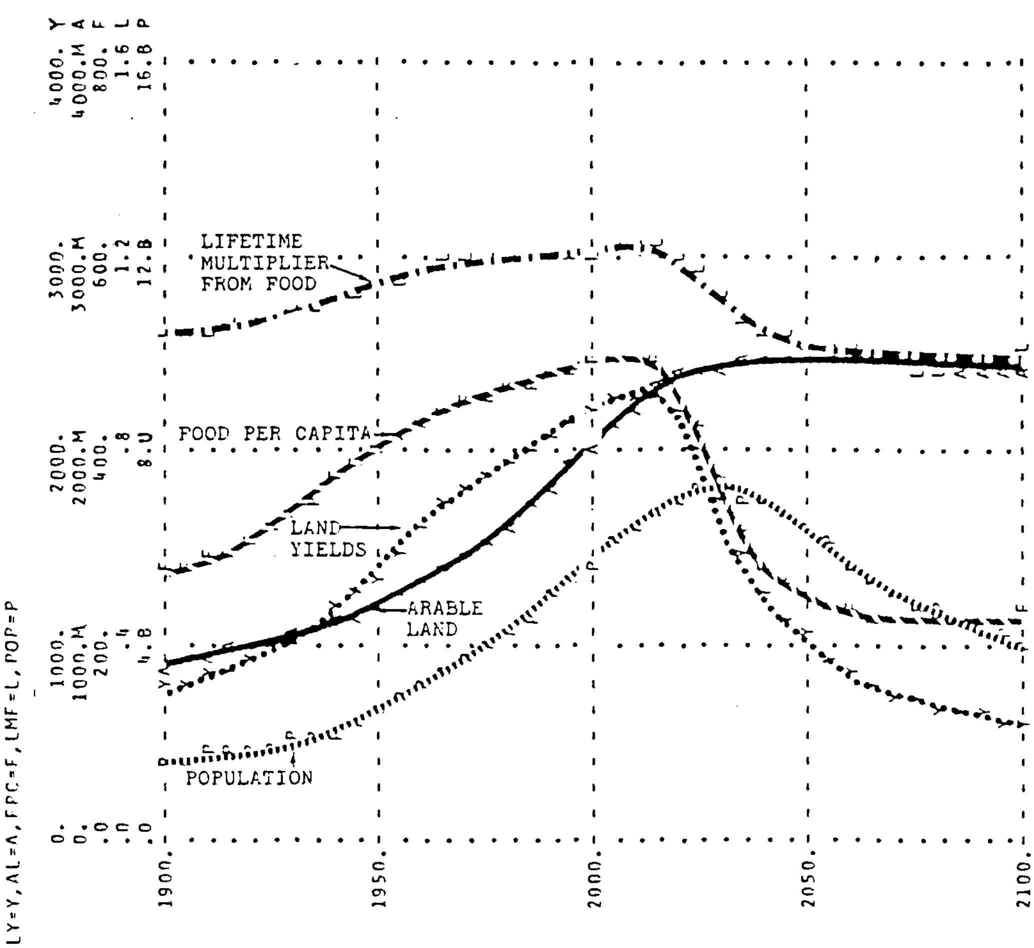

Figure 5-3. Agriculture sector variables from the reference run.

Source: Dynamics of Growth in a Finite World (p. 503) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

is the amount of food per hectare harvested from the arable land (AL) under cultivation (see Figure 5-3). The decline in yields causes food per capita (FPC) to decrease sharply after 2015, and as FPC nears the level of subsistence, the lifetime multiplier from food (LMF) begins to decrease. This chain of causal interactions eventually forces the population (POP) into decline after the year 2030.

While the reference run of World3 produces interesting and rather pessimistic results the modelers offer this "disclaimer" (Meadows et al., 1974):

> It should be emphasized that the reference run is not a prediction of the precise values of any of the model variables in the future, nor does it necessarily represent the most likely behavior mode of the real world. It is termed the reference run only because the output is obtained from the reference model structure and parameters; it is unchanged by any new policies, technologies, or values. The strongest statement of certainty we can make about this run is that it represents the most likely behavior mode of the system if the process of industrialization in the future proceeds in a way very similar to its progress in the past, and if the technologies and changes that have already been institutionalized continue to evolve. (pp. 501-502)

Results of the Standard Run of the World Integrated Model

In executing the standard run of the WIM, the modelers used the assumption that the prevailing historical patterns of development would continue into the future. The modelers examined the impact of these trends on the economic gap, population growth, and natural and energy resource availability. Each of these areas will be discussed below.

The Economic Gap

The results of the standard run of WIM with respect to the question of the economic gap between the already industrialized regions and the regions in the process of industrialization and development are disquieting. Not only does the economic gap between rich and poor regions not narrow, but it increases considerably in terms of ratios and even more so in absolute terms (see Figure 5-4). The gap between the average per capita incomes in the Western industrialized countries grouped according to WIM's classification as the Developed World Region (Regions 1, 2, 3, and 4) and in Latin America (Region 6) will increase from 5 to 1 to almost 8 to 1, or in absolute terms, from about $2000 to more than $10,000 per capita. The situation in South Asia would be even worse. The per capita income gap between the Developed World and South Asia (Region 9) and similarly Tropical Africa (Region 8) would increase in absolute terms from nearly $2500 to $13,000 while in relative terms the per capita income ratio will remain above 20 to 1. It would be virtually impossible to close such an economic gap under prevailing patterns.

Population Growth

To illustrate the population crisis, Figure 5-5 shows population growth from Christ's birth to the year 2000. As can be seen in the figure, it took more than the first sixteen centuries after Christ's birth for the world's population to double in size from 200-300 million to the half billion mark. In the next 200 years another half billion was added and yet another full billion in just 100 years, with the population

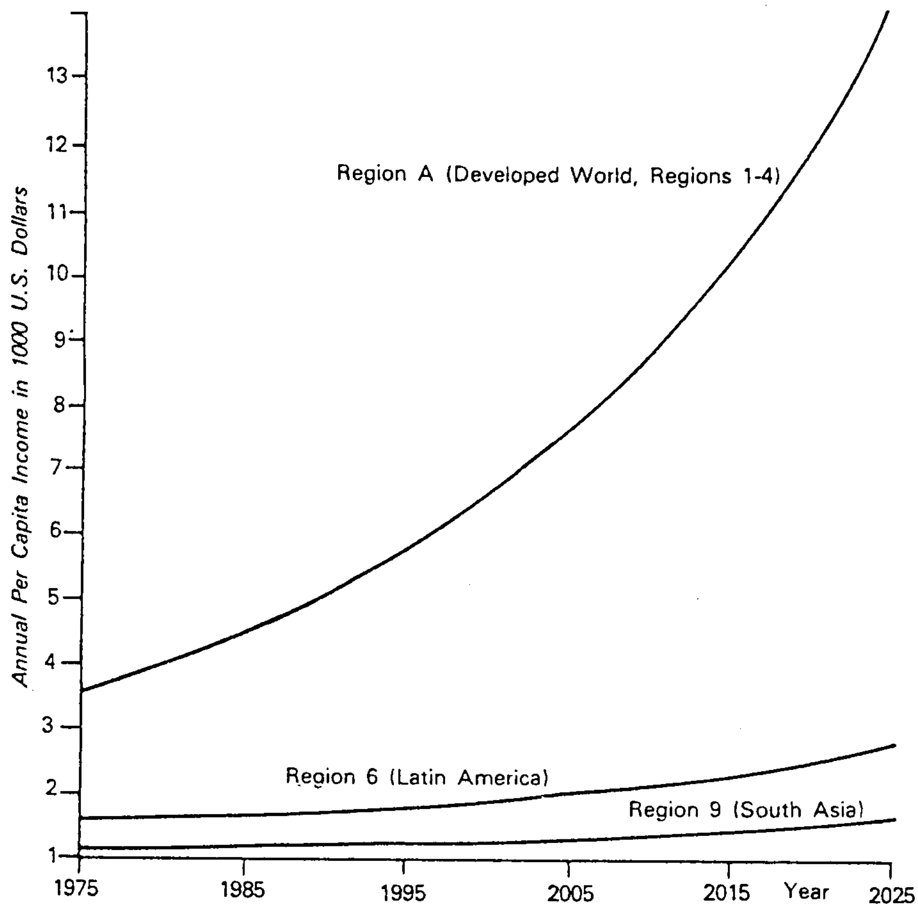

Figure 5-4. Interregional gap as projected by historical developments.

Source: Mankind at the Turning Point (p. 59) by Mihajlo Mesarovic and Eduard Pestel, 1974, New York: E. P. Dutton & Co.

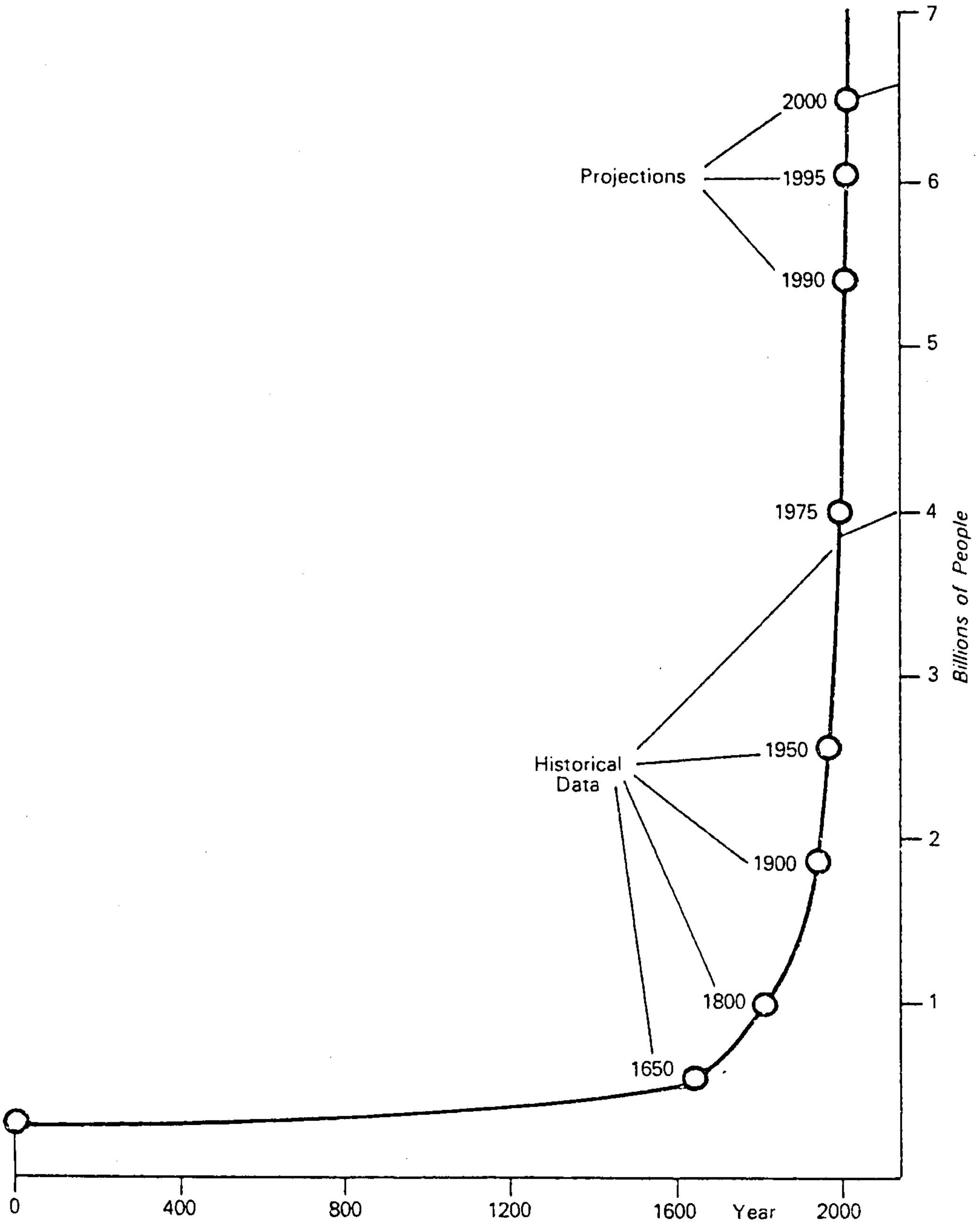

Figure 5-5. World population growth.

Source: Mankind at the Turning Point (p. 73) by Mihajlo Mesarovic and Eduard Pestel, 1974, New York: E. P. Dutton & Co.

reaching a total of two billion around 1930. In the next 45 years the population increased by another two billion. To add two billion more, it will only take another twenty years, with the world population overshooting the six billion mark by the year 2000.

In order to better understand the consequences of such a rate of population growth and the pressure it creates on the economic, social, and ecological supporting system, one has to consider where these additional people will be located. The modelers determined that in order to produce realistic results, an assumption of the implementation of some population control policy was necessary. Specifically, for the standard run, they assumed that in all world regions the fertility rate would decline to an equilibrium level within a fifty-year period, which means that if the fertility rate did not change thereafter the population level would reach equilibrium after an appropriate delay.

The computer analysis indicated that under such conditions at the end of the present century there will be, compared to 1970, an additional four people per square kilometer in North America, but 140 people will be added to the same area in South Asia (Region 9) (see Figure 5-6). This increase alone is more than 60 percent higher than the present population per square kilometer in "overpopulated" Western Europe, where there are at present over 85 people per square kilometer. How this population increase will strain regional resources is indicated by the fact that in the year 2000, for each square kilometer of cultivated land in South Asia there will be 390 additional people to feed--compared with an additional 37 people per square kilometer of

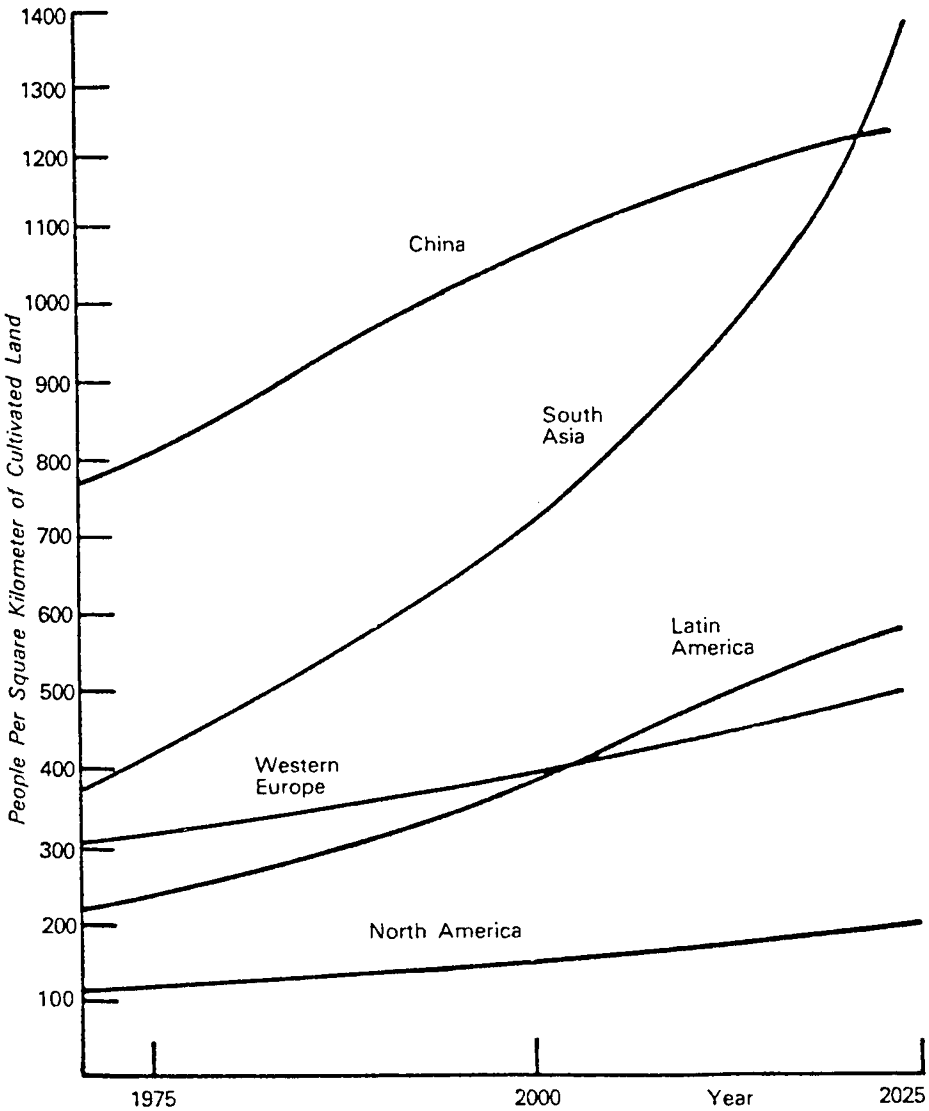

Figure 5-6. Population density related to area of cultivated land.

Source: Mankind at the Turning Point (p. 74) by Mihajlo Mesarovic and Eduard Pestel, 1974, New York: E. P. Dutton & Co.

cultivated land in North America. This population crisis is intensified by the fact that the rate of growth of urban population in South Asia is twice the rate of the total regional population.

Figure 5-7 examines the relationship of urban population growth and unemployment. The growth of urban population will increase in the developing countries especially after the turn of the century when the rural areas will no longer be able to absorb local population increases. This will have the most serious repercussions in the urban labor market, where in the next fifty years nearly one billion new jobs will have to be created in order to absorb the increase in urban population. If the industrial growth rate should be only 4 percent per year, for example, in South Asia (Region 9) alone the number of unemployed urban people would rise to 100 million in the year 2000, and to more than a half billion in 2025, should the present population growth rates persist.

The modelers further examined the population crisis by developing a highly detailed population model. This model accounts for the population by one-year age increments for each of the regions. The modelers then grouped the regions into two categories. The first category is the "North" which comprises the industrialized part of the world (North America, Western Europe, Eastern Europe including the Soviet Union, Japan, Australia, Oceania, and South Africa). The "South" category includes the rest of the world. Overall, under the standard run, based on the historical pattern of development, the model showed that by the end of this century there would be more people in the "South" region than in the entire world today. In another 25 years there would

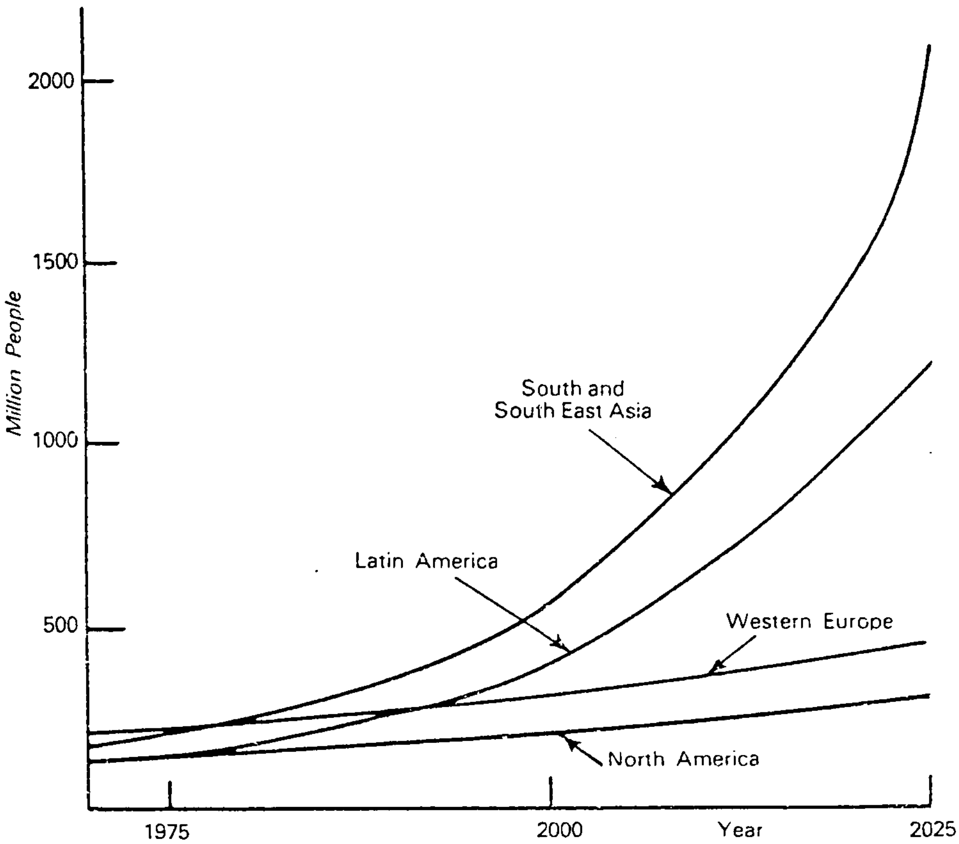

Figure 5-7. Growth of urban population.

Source: Mankind at the Turning Point (p. 76) by Mihajlo Mesarovic and Eduard Pestel, 1974, New York: E. P. Dutton & Co.

be more than three times as many people as in the world today. It is assumed that such a growth rate would have to stop, the only question is whether the halt to such growth will be the result of a deliberate population policy or the result of physical constraints.

With such a phenomenal population growth predicted for the future, the modelers decided to test for the availability of food in the future. The WIM is designed to handle the question of food availability on a regional basis. Diets differ from region to region depending on food availability, terrain, climate, and cultural factors. The WIM determines diets in terms of 26 different types of foods. The model also evaluates the importance of the lack of essential diet components, such as protein, on the various regional populations. The regional nature of WIM allows the model user to analyze the relationship between the location of actual food supplies and the location of actual food and nutrition deficiencies. At the time of the initial run of WIM, the most critical gap between food need and food supply was found in South Asia and Tropical Africa. Due to the larger population in South Asia, the modelers chose this region as their focus for the standard run. Their results, however, are applicable to Tropical Africa and any other needy region.

The purpose of the standard scenario is to provide a clue to the persistency of the food deficiency problem through the year 2025. The scenario (see Figure 5-8) assumes that the historical pattern of development based on a somewhat optimistic view of the past and present situation will continue. It is again assumed that an equilibrium fertility

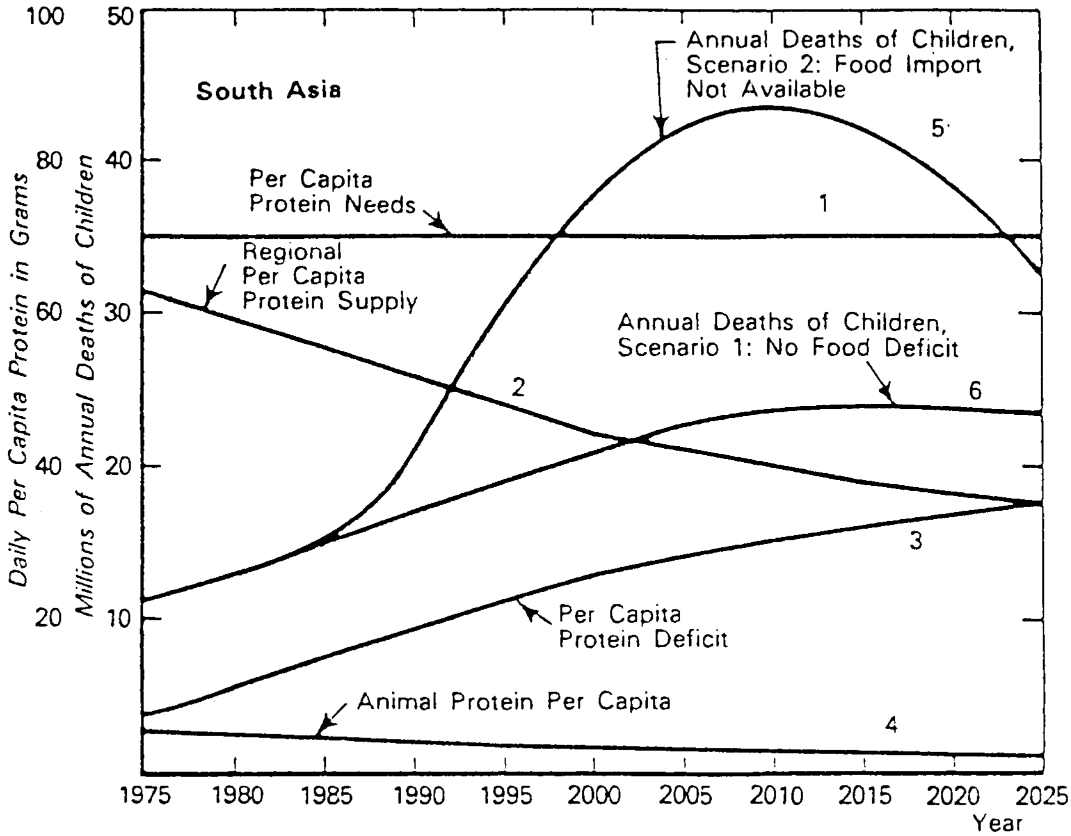

Figure 5-8. Effect of actual food deficit.

Source: Mankind at the Turning Point (p. 124) by Mihajlo Mesarovic and Eduard Pestel, 1974, New York: E. P. Dutton & Co.

level will be attained around the year 2025 and that the average use of fertilizer per hectare in the entire region will surpass the present North American level toward the end of the year 2025. At that time South Asia alone will consume more fertilizer than the whole world consumed in 1960. Assuming that the fertilizer is used on every piece of land under cultivation, the yield per hectare will increase by about 1000 kilograms. The modelers also assumed that all remaining arable land in South Asia was quickly brought under cultivation, and that all technological inputs, such as irrigation systems will be available as needed. Lastly, the modelers assumed that no mass starvation would take place. The food needed to be imported was also assumed to be made available by other regions.

Figure 5-8 is a graph depicting the standard run of WIM with the above assumptions. The horizontal straight line (1) represents the total daily protein needs per person of seventy grams. Curve 2 represents the daily regional per capita protein supply (vegetable plus very low animal protein, see Curve 4). Curve 3 represents the daily per capita protein deficit. All these curves relate to the situation that would exist if South Asia's population were to grow (without starvation-induced higher mortality) from 1.3 to 3.8 billion. If the imports needed to cover this protein deficit were not forthcoming, starvation would take a heavy toll, particularly among children. Curve 5 shows the number of annual child deaths to be expected in such a case (population would grow only to about 3 billion). Curve 6 shows the annual number of deaths of children, if sufficient food were provided through imports. The model's run shows that about the mid-1980s, Curve 5 begins to rise steeply over Curve 6. The decline in the number of child deaths from 2010 exists because, with the exceedingly large number of child deaths after 1985, the age structure of the population is changed so that the children's portion of the total population has drastically diminished, leading, with a fifteen to twenty year delay, to a considerable decrease in the number of fertile women. The total aggregate number of additional child deaths up to the year 2025 amounts to more than a half billion. It should be remembered that these figures are not meant to be accurate forecasts. They are, however, estimates of the magnitude of problems in store for South Asia if the problems of population growth and food supply are not addressed. and food supply are not addressed.

Results of the Basic Run of the United Nations World Model

Since the United Nations world model was developed to test the effects of the requirements set for the world by the International Development Strategy, its results are in a slightly different format. The strategy determined that the average annual rate of growth of gross product of the developing countries as a whole during the Second United Nations Development Decade should be at least 6 percent, with the possibility of attaining a higher rate in the second half of the Decade. It also specified that the average annual growth rate of per capita gross product in developing countries as a whole during the Decade should be about 3.5 percent. The target for growth in average per capita income in the International Development Strategy was calculated on the basis of an average annual increase of 2.5 percent in the population of the developing countries.

If the minimum targets of growth for the developing countries, as set by the International Development Strategy, were implemented continuously throughout the remaining decades of the twentieth century, and if the growth rates prevailing in the developed countries during the past two decades were to be retained in the future, then the gap in per capita gross product between these two groups of countries, which in 1970 was 12 to 1 on the average, would start diminishing even by the year 2000.

It is true that gross product in the developing countries would continue to expand somewhat faster than in the developed countries, and thus the share of the developing countries in total world product would increase. However, because of the much higher growth rates of population, the expansion of gross product per capita would be no faster in the developing countries than in the world as a whole. It is for this reason that the International Development Strategy laid stress on the necessity to accelerate growth starting in the second half of the 1970s in order to make at least a modest beginning towards narrowing the income gap between developed and developing countries.

These considerations provided the modelers with a starting point for the basic scenario for the UN model's initial run. The basic run is called Scenario X and is depicted in Table 5-2. This scenario assumes an average growth rate of 4.9 percent per capita for developing

Table 5-2. Growth Rate and Income Gap Under the Assumptions of Scenario X in the United Nations Model.

	Scenario	Developed Countries	Developing Countries
Growth rate			
Gross product (percentage)	X	4.0	7.2
Population (percentage)	X	0.7	2.3
Gross product per capita (percentage)	X	3.3	4.9
Income gap in the year 2000			
Gross product per capita (index, developing countries = 100)	X	769	100

Source: Future of the World Economy (p. 31) by Leontief et al., 1977, New York: Oxford University Press. Copyright 1977 by United Nations.

countries which is substantially higher than the minimum target set by the International Development Strategy. The growth rate of the population is assumed to be 2.3 percent for developing countries. Finally, Scenario X assumes that the growth rates of per capita gross product in the developed countries decline when higher absolute levels of per capita income are achieved. Therefore, a growth rate of 4 percent per capita is assumed at $3,000 to $3,999, 3 percent at $4,000 to $4,999, 2.5 percent at $5,000 to $5,999 and so forth. This has the effect of bringing down the average growth rate of gross product in the developed countries to 3.6-4.0 percent from the long-term trend of 4.5 percent.

Scenario X is further broken down into regions. Table 5-3 shows the growth rate and share of gross domestic product (GDP) by region for the period of 1970-2000 for Scenario X. As can be seen in the table, the over all more rapid growth of the developing countries would bring about a significant increase in the share of these countries in total world GDP. In fact this share would be doubled by the year 2000 reaching about 22 percent for the developing market regions as a whole. According to Scenario X, the developed centrally planned economies of Europe would continue their over all expansion at a rate somewhat higher than the world average, and their share in the world total would also increase. Most of the developed market economies would expand at rates below world averages, and their total share would decrease to about one half as compared with the present two-thirds.

Table 5-3. Growth Rate and Shares of GDP, by Region, 1970-2000, for Scenario X.

Region	Average Annual Growth Rate (percentage)	Regional GDP as a Percentage of World GDP	
		1970	2000
Developed market		66.1	50.9
North America	3.3	32.9	21.0
Western Europe (high-income)	3.7	22.6	16.7
Japan	4.9	6.2	6.5
Oceania	4.5	1.3	1.2
Southern Africa	7.5	0.5	1.1
Western Europe (medium-income)	7.0	2.3	4.4
Developed centrally planned		18.6	20.7
Soviet Union	5.2	13.5	15.4
East European	4.9	5.1	5.3
Developing market		11.1	22.0
Latin America (medium-income)	7.1	3.5	6.9
Latin America (low-income)	7.2	1.2	2.5
Middle East	9.0	1.1	4.0
Asia (low-income)	6.7	3.8	6.6
Africa (arid)	5.5	0.8	1.0
Africa (tropical)	6.5	0.7	1.0
Developing centrally planned	6.3	4.2	6.4
Developing as a whole, including Asia (centrally planned)	7.2	13.3	28.4

Source: Future of the World Economy (p. 32) by Leontief et al., 1977, New York: Oxford University Press. Copyright 1977 by United Nations.

In setting the exogenous growth rates the modelers made no special attempt to estimate the relative purchasing power parities of national currencies, and gross products in many cases are compared in terms of official exchange rates. Therefore, the ratios given in Table 5-3 should not be taken as representing true comparisons of absolute product volumes but rather as an indication of the direction in which they are expected to change.

While the gross domestic products of the developing areas on the whole are expected to increase at higher rates than the world average, substantial differences among the growth rates of the individual regions are indicated in Scenario X. The Middle East is expected to grow at average rates of close to 9 percent, Latin America at 7 percent, and arid Africa at 5.5 percent. These differences are in part based on disparities in present growth rates, from which the development possibilities have been estimated.

Therefore, 1970 growth rates of GDP are estimated to be only 4.5 percent in arid Africa, 5.0 percent in Tropical Africa and low-income Asia, 5.5 percent in both Latin American regions and 11.9 percent in the Middle East. Though growth rates for all developing regions (excluding the Middle East) do increase as they approach the year 2000, it takes a longer time for arid and tropical Africa to reach significantly higher rates of growth.

It is also important to note that the starting levels of per capita GDP are very different in various developing regions. As seen in Table 5-4, this makes it difficult for some regions, especially for low-

Table 5-4. Per Capita GDP in Developing Regions, 1970-2000, for Scenario X

Region	1970	2000
Middle East	286	1,149
Latin America (low-income)	443	1,577
Latin America (medium-income)	594	2,149
Developing centrally planned	167	681
Asia (low-income)	120	401
Africa (arid)	205	436
Africa (tropical	141	399

Source: Future of the World Economy (p. 32) by Leontief et al., 1977, New York: Oxford University Press. Copyright 1977 by United Nations.

income Asia, arid Africa and tropical Africa, to approach the relatively low-income target of $500 per capita by the year 2000. To achieve this goal, low-income Asia would have to increase its GDP at an average annual rate of 7.5 percent, arid Africa at 6.0 percent, and tropical Africa at 7.3 percent. While such growth rates are not impossible, they would still imply per capita incomes in 2000 which are higher than current average incomes in Latin America. The modelers determined that the income situation in low-income Asia, arid Africa and Tropical Africa would continue to be an acute problem in the twentieth century, and that international attention and effort favoring the development of these regions was necessary.

Differences in Model Results

The results of the basic runs of the three models examined here differ mainly due to three factors: (1) the different methodologies employed, (2) the assumptions set by the modelers, and (3) the original purposes for which the models were developed. While forecasting different results, the various analyses offer more information in varying degrees of breakdown and under various assumptions. By comparing one model's results to another while taking into consideration the methodologies and assumptions used a better view of the future can be obtained.

Population

In comparing the results of the basic runs of the three world models mentioned above, many differences can be found. While all three models discuss population growth their results are somewhat different. The basic run of World3 forecasts a world population of six billion by the year 2000 which will increase to seven billion by the year 2030. In relation to this population growth, the industrial output per capita will reach a peak in 2015, while persistent pollution will reach its peak by the year 2035.

The basic run of WIM examines population growth to a greater degree then World3. Like World3 it has the world population reaching the six billion mark by the year 2000. Then, based on the assumptions discussed in the previous section, the modelers went on to examine the population growth in greater detail. The model examines the geographical breakdown of the forecasted world population. The model shows that by the year 2000 there will be more people living in the developing regions of the world than there are in the entire world today.

The basic run of the UN world model looks at future population growth in yet another manner. Since the model was developed to test the effects of the requirements set for the world by the International Development Strategy, its results are in a different format from those of World3 and WIM. For the basic run of the UN model, the modelers set an exogenous population growth rates for developing and developed countries. It then uses these rates to examine the rate of growth of Gross Domestic Product in the various countries.

Food Availability

The results of the basic run of World3 examines agricultural investment in relation to industrial output. Specifically, World3 forecasts that the fraction of nonrenewable resources remaining will drop below 0.5 in the year 2015. This will cause the fraction of capital that must be allocated to obtaining these resources to rise above its minimum level. Therefore, industrial capital is diverted from the production of industrial output toward obtaining the resources necessary to sustain that output. As the total of industrial output declines, the total agricultural investment is also forced to decrease. The result is a decline in food per capita to a point near subsistence after 2015.

The basic run of WIM handles the subject of food availability on a regional basis. The model also determines diets within these regions in terms of protein needs. The results of the model's analysis in this area forecasts a great protein deficiency in the diets of the developing countries, resulting in a large number of deaths among children by 2010. It also forecasts a large starvation rate in these countries if the imports needed to cover this protein deficit are not received. The effects of this trend are expected to be most severe in South Asia.

The basic run of the UN model does not deal with agricultural problems in the future. This is due once again to the nature of the purpose for the development of the world model for the United Nations. The forecasts for agriculture can be found in subsequent runs of the model.

The results of the basic run of WIM include one area of analysis that is not included in the other two models' basic runs. This is a forecast for the economic gap between rich and poor regions of the world. The model results reveal a widening of the gap to a point where closure is an impossibility. The UN model also includes an area of analysis not covered in the basic runs of the other two models. This is a forecast for the growth rate and share of Gross Domestic Product for the various regions of the world. The effects of the increase or decline in GDP on population, agricultural production, food availability, and capital and industrial output are all calculated in subsequent runs of the UN model.

Similarities in Model Results

Despite the differences found in the individual results of the basic runs of the various models, there seems to be a certain degree of consensus among them. For example, all the models predict that major problems will take place on a global scale around the turn of the century, marking the beginning of a period of transition to a new social and economic order. All of the models project possible crisis by the year 2000 and beyond, but the authors also agree that these crises can be overcome by prompt international and cooperative action. Following a period of transition, the most probable outcome appears to be some new, relatively stable state. The social, economic, and political structure of society in this period cannot be ascertained even dimly.

However, it will be critically influenced by decisions (and nondecisions) made during the transitional period.

All the models also agree that if the current population growth rate were to continue into the future the result would be severe demands on the finite resources of energy, minerals, space, and food in the short and middle run. Consensus has also been reached on the fact that some regions of the world will suffer more drastically and sooner than other regions. South Asia, arid and tropical Africa and to some extent, Latin America are all pinpointed as regions that are facing severe life-threatening problems in the near future. What is offered is the hope that a "demographic transition" may occur as a result of favorable developments in the agricultural, energy, and economic sectors. There is wide agreement that, barring an intervening crisis, the world will have to support about two billion more people by the year 2000. Unfortunately, the results of the models for arid Africa have already borne true in 1985 as the "intervening crisis" of severe multi-year droughts has brought that area of the continent to its knees with tens of thousands lost to starvation.

Lastly, the models agree that it is quite probable that the "gap" between the rich and poor nations of the world will increase in the future. Specifically, they all agree that without concerted action, it is improbable that the gap will diminish. Even the most conservative of world models proposes that substantial transfers of resources take place from the rich to the poor. All the modelers also agree that it would be advantageous for these transfers to occur sooner rather than later.

CHAPTER 6

THE FUTURE OF WORLD MODELING AND IMPLICATIONS FOR NATIONAL PLANNING

The use of world models in making policy decisions requires the awareness of several facts. First, potential modelers must be realistic about what can be achieved with a modeling effort. Model users must also realize that even with all the best resources available there are limits to what can be achieved in using a world model. They should be aware of the trade-offs involved in the use of resources to attack the problem in nonanalytical ways.

Another matter model users need to be aware of is the fact that most of the world models that exist today reflect the model builder's perception of the world. This, in turn, has the effect of reducing the validity of the model. This is not necessarily bad as long as the model user realizes the approach under which the model was produced. Finally, it is important for the effective use of a model that it be carefully and realistically evaluated and updated.

On the whole, it should be remembered when using world models that they can (1) be developed, even within the very real constraints of available data and current technology; (2) be validated with respect to the assumptions upon which their development was based; and (3) be useful, within the constraints of appropriate application. However, world models cannot (1) predict the future; (2) produce reliable output from unreliable data; and (3) be validated except in a limited sense.

No model is perfect and world models certainly do not claim otherwise. Among the many limitations of world models there are those that are inherent to the nature of the modeling and others which are due to the time period in which the models were developed. Both types of problems will be discussed in this chapter.

Limitations Common to All World Models

The inherent problems of models the size and complexity of world models are worthy of the attention of both model builders and users. The three most important problems tend to be (1) data collection and availability, (2) calibration and validation of the models, and (3) the quantification of social factors into the model.

Data Collection and Availability

In the 1930s, many of the developed nations initiated the collection of extensive national accounts data. In the postwar period, many governments also began to report input-output data. Consequently, an extensive body of data is available to support the modeling activities of economists. In other areas of inquiry and in the developing nations of the world, the situation is quite different.

Conceptually the problem is quite simple. Today's data bases have imbedded within them the structure of yesterday's problems. The lag time between the identification of a new problem and the availability of extensive data to study it is measured in years, sometimes decades. World modeling, as a field, is no more than nine or ten years old, although some of the problems addressed by world models have been studied for much longer periods of time.

In particular, world modelers face four serious data problems (Richardson, 1978):

1. To develop a relatively complete model, data is needed on the centrally planned economies, the developing nations, and China. Most of these data are sparse or simply non-existent.
2. Even in the developed nations, significant data gaps exist at the interfaces between sectors. The consumption of energy by the agricultural sector, the consumption of water by certain classes of industry, the generation of pollution, etc., are examples. Moreover, serious problems exist in linking data which measure productive activity in terms of commodities and data which measure such activity in monetary terms.
3. There are almost no useful data available of social and institutional phenomena for any nation, nor even on critical human needs such as health, housing, nutrition, and employment.
4. To model many of the problems of concern to world modelers, not only average data but distributional data are important. The latter are rarely available. (p. 169)

There are no easy solutions for these problems. Moreover, most modeling projects are based on essentially the same nationally collected data, sometimes filtered through United Nations organizations. Each project has devised a somewhat different approach to collecting, structuring, storing, and retrieving data. Among the economic modelers, who operate within a common paradigm, there has been a degree of cooperation (input-output tables are widely discussed and shared). Elsewhere, the extent of sharing has been less.

Out of the three world models examined in this study, World3 has the least problem with data constraints. Forrester, (cited in Cole, 1977) said:

> A system dynamics model is very different from the more common econometric models by being drawn from a much broader information base, by representing more generally the nonlinear character of real life, by containing a deeper internal substructure of policies, by including social and psychological variables as well as the strictly economic variables. (p. 64)

Systems dynamicists, therefore, tend to view lack of data as less of a constraint than other modelers. Even so, the modeling team of World3 has been quoted as estimating their model on only 0.1 percent of the data required to construct a world model (Cole, 1977, p. 64), yet the model is recommended for policy purposes. The claim here is that the models are better able to utilize even what limited data is available. Even where sufficient numerical data are not available modeling is still possible. As Forrester (cited in Cole, 1977) stated there is a "wealth of information," already available in written or numerical form, and much drawn "from experience and observations residing in people's heads" (p. 64). Forrester's original World2 model, in fact, contained no formally collected data whatsoever other than estimated global population in the year 1900 and 1970.

Other modelers are more cautious than system dynamicists and mainly prefer to rely on more conventionally collected data. Consequently, a great deal of effort is involved in their studies in the collection of consistent sets of data. Nevertheless, assumptions are being made about the areas formally excluded from the model. The defects of data availability have already been discussed. In particular, some of the more obvious difficulties include the different definitions used for sectoral divisions in different currencies or physical units into a common calculus. Demographic data also has well known deficits especially for developing nations where official statistics may be based on a 1 percent census. Environmental and ecological data is even more limited and its interpretation especially exposes many pitfalls.

Out of the three models examined in this study, the greatest effort in terms of gathering economic (sectoral and trade) statistics has probably been for the United Nations world model. Some of the major data collection problems encountered by the modeling team are summarized by Leontief (cited in Cole, 1977) in the following manner:

> Individual country (input-output) tables are constructed with different classifications and accounting conversions, and expressed in terms of their own price units. Years of painstaking analysis and data refinement would be necessary before we could construct individual country tables to construct meaningful regional tables. Furthermore, for several of the developing regions there were only one or two country tables available, and for China and some of the African regions there were none. The same sort of problems made it impossible to observe directly the composition of consumption and investment expenditures in each region. In the absence of adequate region specific data it was necessary to estimate many, but by no means all, of the structural coefficients of the system as functions of per capita gross national product on the basis of cross country regressions. (p. 65)

In the UN world model, the data is assembled for a single time period. The coefficients are taken as averages for the full ten year period. The matrix is updated at each time step on the basis of cross-sectoral data established for the base year time period and estimates of how other variables might be expected to change in the intervening ten year periods. Therefore, growth in the world economic system is in part imposed by assuming a given rate of growth will occur in the ten year interval although, of course, the rate must be more or less consistent with the other changed assumptions. The final internal consistency is obtained by allowing levels of investment to adjust so as to balance inputs and outputs throughout the model.

In both World3 and WIM the assumptions about change are largely (although not entirely) built into the models as causal or time dependent relationships. The numerical values in these models have to be based on the data for a series of years rather than a single year. Therefore, the data requirements for these two models are somewhat larger than those for the UN world model.

According to the UN world model modeling team (cited in Cole, 1977):

> The task of assembling data for the world system involved two major endeavors: the estimation of structural coefficients for each region in the base year of 1970 and the projection of changes in these base year coefficients for the years 1980, 1990, and 2000. Both of these efforts posed serious problems and it would be presumptuous to claim any degree of statistical authority even for the base year data. Estimates of future coefficients are, for obvious reasons, even more uncertain. . . . It is our belief that the estimates while rough are generally plausible and that they provide a solid basis for future improvements. (p. 66)

In dealing with the problems associated with data collection and availability, world modelers tend to practice one of the following five approaches. First, if the desired data is unavailable, the phenomena which the data would measure is excluded from consideration in the model. Many of the modelers for whom economics is the principal frame of reference tend to adopt this philosophy and to justify it on the grounds of theory as well as pragmatism. However, to some degree, the approach has been used by all world modeling projects. The exclusion of critically important social and institutional considerations has normally been justified on the above grounds, if it has been justified at all.

The second approach is also applied when the desired data is unavailable. In this case the phenomena which the data would measure is included in the model and the modelers rely on the best judgement of team members or other knowledgeable individuals to fill in the gaps. System dynamicists tend to be the strongest proponents of this approach. There are probably no world modeling projects in which judgement has not been used to fill at least some gaps in data.

The last three approaches used by world modelers are to generalize unavailable date from existing data at another level. For example, one approach is to generalize from case studies and field experience to fill in gaps in data at the national and regional levels. To some degree, almost every modeler is likely to generalize from his own specialized experience if it appears to be relevant to the filling of a gap. Another data generalizing approach used by world modelers is to generalize from the national level to the regional level to fill in the gaps. Lastly, world modelers also generalize from the data of one nation to fill in missing data for another.

In the long run, many of the data problems facing world modelers will be resolved by growing national attention to global problems and consequent national data collection efforts. In the short run, however, much could be done to make the data bases of the respective projects widely available in a central location. Because of a failure to do this, much valuable work has been lost as projects concluded. Moreover, since world modeling projects are in the business of developing models, not developing and disseminating data, this aspect of the work tends to receive little attention. Some organization with sufficient resources and continuity, possibly the International Institute for Applied Systems Analysis, should make this problem an urgent high priority item on its agenda for future work.

Calibration and Validation Problems of World Models

The calibration of a large model is a very complicated process the difficulty of which is increased by the fact that there are no standard procedures for establishing the validity of the model. With the exception of checking individual relationships, most significance tests derived from standard statistical methods and short-term econometric modeling are not applicable in the case of world models.

Usually calibration of a model takes place in two stages: matching various individual relationships in the model to available data and then bringing the individual relations together into a model and demonstrating that this model does in fact reproduce the historical behavior of certain variables. For world models containing submodels (e.g. World Integrated Model) there is an intermediate stage where each submodel is separately tested using historical data. In an input-output model the check with historical behavior is carried out by merely comparing the average values predicted by the model with historical data.

World2 calibration, as such, was established by allowing the model to reproduce trends from 1900 to 1970 and asking readers to assure themselves that these were reasonable. For World3, relationships of each subsector of the model (e.g. population) were calibrated on whatever data was available and tested separately. The complete model was assembled and adjustments made to ensure that all plausible results were obtained for the 1900-1970 time period. According to the modelers, "From 1900 to 1970 the variables plotted agree generally with their historical values to the extent that we know them" (Meadows, Meadows, Randers, & Behrens III, 1972, p. 131). In other words, a general plausibility of the historical behavior of the model is argued. As pointed out by the World3 modelers, "the problem of validity is handled qualitatively and informally" (Meadows, Meadows, Randers, & Behrens III, 1972, p. 26). This is partially justified by system dynamicists on the grounds that the very concept of validity is somewhat indeterminate.

In other models a rather more precise comparison with historical data is made but over a much shorter time period. For the WIM, comparisons are made of model parameters and historical data for selected variables between 1950 and 1970.

The crucial question arises of whether, even if a model does provide a satisfactory check on history, under what conditions does this mean anything for the future. As mentioned before, none of the modelers claim to be predicting the future and all forecasts are conditional. The World3 forecasts were conditional on the continuation of "present trends" and the alternatives conditional on certain global policy actions. This is true of all other models. On the other hand, the value of the models is in part justified by authors through the success with which they explain the past. Whether this can be considered a validation of those parts of the model which are not changed in considering different "scenarios" rests on whether the relationships and data concerned are invariant through time. This applies both at the level of the overall structure of the model and the individual relationships it contains.

It is evident that in making alternative assumptions, modelers are apparently constrained by lack of data and by technical considerations. In attempting to describe the long-term future the modeler is caught between making bold and largely unstable assumptions about the future and constraining the range of possibilities considered by tying himself as closely as possible to the rather unsatisfactory data available. Very often it seems that modelers can do nothing but resort to adjusting their results until a plausible future is portrayed. Growth rates must not be too high nor too low but in any case goals must be achievable using the strategies proposed. The gap between the limited attention that the World3 modelers pay to data and calibration and the more careful analysis of the other models is to some extent more apparent than real.

However, even if data were perfect, many controversies would remain. It cannot be proven, for example, that current cross-sectional fertility rates provide a sufficient indication of these rates for developing countries in the future, nor is it the case that United States style of technology transferred to developing countries should be described by its historical coefficients of production or that consumption patterns across the world, however similar they are now, need necessarily to be considered inevitably similar in the future. All these assumptions are debatable and which parameters to assume to be invariant and which not, is ultimately a matter of opinion. Yet, all of them can be very important to the results of the models.

Problems with the Quantification of Social Factors in World Models

Complex social systems can be described in terms of their connectedness which is illustrated through positive and negative feedback loops as used in World2 and World3. As evaluation proceeds from variable to relations to linkages, the criteria become less clear. At the same time, however, the evaluation becomes more concerned with the creativity and ingenuity exhibited in the model. In this way, problems encountered at the more mechanical level may be compensated for by creative solutions where standard procedures and hard data on the real world are missing.

World modeling has often been attacked on this point. The World3 model received the majority of this criticism due to its large popularity upon publication. The inclusion of social values into the model was discussed in Chapter 2 and includes such factors as longevity, children, material goods, and education. Some of these values are represented explicitly in the model as variables that have an important influence on economic decisions. Others are included implicitly, for example, in the allocation of service output to health services or in the quantity of nonrenewable resources used per capita.

All of the values included in World3 are assumed to be responsive to the actual physical and economic condition of the system and thus they are involved in feedback loops. However, the patterns of dynamic value change included in the model are limited to the patterns of change historically observed in individual countries over the last hundred years or so. During that time the major force behind value change in the world system has been the process of industrialization, a process that is still underway in most of the nations of the world. Therefore, the values that both shape and respond to the development of the model system follow the historic pattern of industrialization. As industrialization increases in the model the aggregate social demand in the model shifts in emphasis from food to material goods and finally services. Other changes occur in reference to preferences for children, education, and health care, and in the distribution of various goods and services throughout the industrializing population.

Of their representation of human social values in World2 and World3 the modelers have stated (cited in Cole, Freeman, Jahoda, & Pravitt, 1973):

> Human values, like human technologies, may evolve in the future in directions we cannot possibly foresee at this moment in history. Therefore we cannot build into World3 any global shifts in values other than those that might be expected to take place as the world becomes more industrialized. Again, the model cannot predict value changes, but it can serve as a test device to show the results of any given assumption about the future evolution of values. Therefore, we have also included, in several model relationships, test switches that can

> be used to activate postulated value changes at any data specified by the operator. (p. 235)

Mathematical models must be evaluated as part of the cultural context within which they are constructed. This relation exists because every model of a social system must omit some details of the real world. A model is intended to be a simplified version of a complex system. It is constructed to improve understanding of the nature and implications of actions within the real-life situation.

Due to this nature of modeling, human interaction is involved in the choice of the issues addressed by a model and in the identification of those less important details that may be eliminated without subtracting significantly from the purpose of the model. Therefore, every model is influenced by prevailing social values and goals. "In short, there is no model useful for understanding all issues and no 'scientific' or 'objective' way to construct a perfect model" (Cole, Freeman, Jahoda, & Pravitt, 1973, p. 235).

Limitations of World Models Due to Being Outdated

In addition to the three limitations of world models discussed in the previous section are limitations of world models due to the date of the model's development. In order for any model to be a productive and efficient tool it must be periodically reviewed and updated. The three models examined in this study have had very little updating since they were first developed. The world has taken on many different directions since these models were developed. In order to be used today, these models would require a substantial amount of updating.

Even though the limitations inherent in the modeling process would still remain, modifications in the form of the addition of factors to the models would go a long way toward making the models more effective for decision-making today. While there are many new trends and technologies to be included in these models, this study will touch on just four factors that have become crucial to the existence of the world population and the planet as a whole. These four factors are (1) climate, (2) acid rain, (3) thermal pollution, and (4) the increased use of nuclear power.

Climate

Climate as a whole needs to be included in world modeling efforts. At the present, climatic interactions are not understood well enough to produce models to predict future climatic trends. What is needed is information on variability and probable extremes. The lack of available of data is a serious problem in this area of analysis. Enough has happened to the Earth's atmosphere in modern time, however, to make it necessary to start to pursue this problem and to find ways to collect this data. Some of the recent changes in our atmosphere involving acid rain and thermal pollution will be revealed in the following sections.

Acid Rain

A study conducted by the Council on Environmental Quality and the Department of State entitled the Global 2000 Report to the President, predicted a 13 percent increase in coal combustion by 1990. This increase will significantly increase the production of the two primary causes of acid rain--sulfur oxides (SO_X) and oxides of nitrogen (NO_X). The 58 percent increase in oil combustion projected to occur by 1990 will also increase both SO_X and NO_X emissions; the 43 percent increase projected in natural gas combustion will increase NO_X emissions. Technologies are available to remove sulfur oxides, but their removal is expensive and probably will not be required uniformly throughout the world. The water-quality consequences of increased emissions, especially increases of NO_X emissions, need to be considered carefully.

The immediate consequences of both SO_X and NO_X emissions is the acidification of precipitation. These gaseous compounds react in the atmosphere to form sulfuric acid and nitric acid, which, in turn, precipitate out of the atmosphere in both rain and snow. The acidified precipitation falls anywhere from a few hundred to a few thousand miles away from the source. Consequently, highly acidic rainfall has been experienced in Sweden, Scotland, Norway, Eastern United States, Canada, Germany, Eastern Europe, and Soviet industrial areas. The effects of acid rain are only now beginning to be understood and have been observed in lakes, rivers, and forests, in agricultural crops, in nitrogen-fixing bacteria, and in soils.

The 13 percent increase in coal combustion by 1990 implies that large areas in and near industrial areas will continue to receive highly acidic rainfall. These affected areas are likely to extend hundreds to thousands of miles downwind from the sources, a total geographic area large enough to include many lakes, watersheds and farmlands. The combined adverse effects in these areas on water quality and indirectly on soil quality and plant growth are likely to become increasingly severe.

Thermal Pollution

Carbon dioxide (CO_2) is a colorless, tasteless, nontoxic gas. It is a basic product of the combustion of all hydrocarbons, including fossil fuels and wood. It is not subject to economically practical control by any pollution-control technology. The amounts of CO_2 produced annually are so large that the only possible means of disposal is discharge to the atmosphere.

The carbon dioxide content of the atmosphere has been increasing since routine observations began. Preindustrial (ca. 1860-1890) atmospheric CO_2 content is estimated by most experts at approximately 290 ppm (parts per million by volume); measurements show the 1976 content to be 332 ppm and the 1982 content to be 342 ppm. Average concentration has increased by about 5 percent in the twenty year period of 1958-1978.

The increasing atmospheric concentration of CO_2 is of concern because of the so-called greenhouse effect. In a greeenhouse, shortwave solar radiation from the sun passes through the glass and is reradiated as infrared longwave, heat radiation from the soil and other surfaces inside the greenhouse. The heat energy radiated upward is trapped inside of the greenhouse by the glass, which cannot transmit longwave radiation to the colder outside environment. The CO_2 in the atmosphere acts in much the same way as glass, permitting solar radiation to pass through to the earth's surface but intercepting some of the heat radiated upward from the surface toward space and reradiating it back toward the surface. With steadily increasing atmospheric CO_2, the balance between incoming and outgoing radiation can be maintained only if surface and lower-atmospheric temperatures increase.

Carbon dioxide is also released into the atmosphere by burning wood and fossil fuels. The development of agriculture, the conversion of forest land to sparsely vegetated farms, has moved carbon atoms from plants on the ground to carbon dioxide in the air. About half of this new CO_2 is removed by plants or by the layering down of carbonates in the oceans. Once the CO_2 is in the air our present technology is unable to remove it. If no other factors intervene and if enough CO_2 is put in the atmosphere, eventually the average surface temperature will increase.

The National Academy of Sciences estimates that the present atmospheric abundance of CO_2 is likely to double by the year 2065, although experts there predict a one-in-twenty chance that it will double before 2035. Such a doubling would warm the air near the surface of the Earth by 2°C or 3°C--maybe by as much as 4°C. There would also be precipitation changes in that the annual discharge of rivers would be altered. As the climate warms, glacial ice melts. Over the last 100 years, the level of the world's oceans has risen by six inches. A global warming of 3°C or 4°C over the next century is likely to bring a further rise in the average sea level of about 28 inches. An increase of this magnitude could induce fundamental changes in the patterns of land development. There is also speculation that a greenhouse temperature increase of 3°C or 4°C could, in addition, trigger the disintegration of the West Antarctic Ice Sheet, with huge quantities of polar ice falling into the ocean. This would raise the sea level by twenty feet over a period of centuries.

Nuclear Energy

Nuclear power has several important societal and environmental problems associated with its widespread use. These include concerns related to reactor safety, nuclear waste disposal, and international security.

Nuclear reactor safety is a continuing issue. The possibility of a truly catastrophic accident, involving a reactor meltdown that releases considerable amounts of radiation and could lead potentially to thousands of deaths and billions of dollars of property damage, has been a concern since the beginning of the technology. If nuclear power plants are not subject to careful design, maintenance, and management, these facilities pose great risks to public health and welfare.

The total global amounts of nuclear waste generated by reactor operations have grown steadily. Nuclear waste products are toxic, highly radioactive, and long-lived. Some of the radioactive isotopes in nuclear wastes remain radioactive for hundreds of thousands of years. Research must be done to find the best and safest way to dispose of nuclear wastes. Water quality has suffered greatly due to nuclear waste. According to the Global 2000 Report to the President done by the Council on Environmental Quality and the Department of State, (1980), there are three broad types of radioactive species in the marine environment. The first species are transuranic elements used as nuclear fuels, such as uranium, neptunium, curium, and plutonium. The second species is the radionuclides produced as fission products or as induced radioactive species, such as strontium-90 and cesium-137. The last of the three types of radioactive species found in the marine environment is the activation products resulting from the interaction of nuclear particles with the components of nuclear reactors and weapons, such as zinc-65 and iron-55. As early as 1972, scientists had detected 52 artificially produced radionuclides in the marine environment. In the decades ahead, the largest source of radioactive materials entering the oceans will probably be from the nuclear fuel cycle, i.e., the production, use, reprocessing and disposal of nuclear fuels.

It is not known to what further levels the various radioactive elements could safely be accommodated in the marine environment, especially in crucial coastal zones. Transuranics, fission products, and induced radioactive species are now found in seawater and in the ocean biota almost universally. The biological or environmental significance of this contamination is unknown.

Nuclear power may also increase the risk to world security, both through the possibility of added vulnerability to terrorist actions and through its potential for accelerating the proliferation of nuclear weapons. Acts of vandalism and sabotage have already occurred in several countries. The spread of sensitive facilities (e.g. enrichment and reprocessing plants) can result in direct access to weapons-usable materials. The widespread use of plutonium and highly enriched uranium would increase the availability of both, and also increase the risk of further proliferation of nuclear weapons throughout the world while offering no substantial advantage over the continued use of low-enriched uranium in the nuclear energy facilities of those nations that do not now have nuclear weapons. Furthermore, a substantial disadvantage could occur in that a proliferation of nuclear weapons capability could diminish world security and in turn threaten the energy security of all nations.

Directions for Progress in World Modeling

Overall, there are several new directions in which world modeling could and should progress into the future. In summary, there should be more emphasis placed on the following in world models: (1) soft variables--political, social, and institutional factors, (2) close day-to-day working relationships between models and decision-makers (models and modelers should be an integral part of the decision-making process), and (3) the updating of sectors and factors that represent our world system as it changes through time.

There are also things that model users and builders must learn in order to ensure that world models will be put to their best use. In particular, model users and builders must learn to: (1) quantify data that have previously been considered unquantifiable, (2) develop modeling techniques to better deal with the unpredictable, (3) better determine the relative importance of characteristics of the system to be modeled, (4) recognize and compensate for the inevitable biases that creep into world models and the analysis of their results, (5) ensure that models are not used for purposes beyond their capability, (6) establish flexible standards for meanings, terms, documentation, and methodology, (7) educate the modeler concerning policy-making and the policymakers, that is, concerning the environment in which the model is to be used, and (8) educate the potential user as to the capabilities and limitations of world models.

What is suggested above is a big order. However, as the world progresses, and humankind with it, the interactions and relationships among its various parts become more and more complicated. In return our reactions and answers to these new dilemmas and complex situations lead us to the point of having to depend on more than just our own highly subjective mental models of our environment. In short, necessity has pushed us into a world of large-scale models for the purpose of policy-making. This, in turn, has created a challenge for the modeling profession that can only aid in producing more efficient and effective models. The age of information technology and computerization has also gone a long way to aid in the production of complex and complete world models.

Importance of a Global Outlook in Planning

There can be little debate about the continued relevance of the issues and perspectives raised by the Club of Rome and the three world models examined in this study. In particular, it is essential that the potential long-term consequences and the global consequences of national decisions be taken into account. Nor can there be much debate about the need to supplement the mental models of decision-makers with more formal models in the case of world-wide matters. The question, then, is not necessarily whether world models should be used but what kind of model, developed by whom, incorporating what methodologies, and in what context.

It is now possible to take hypotheses about the separate parts of the world system, to combine them in a computer model, and learn the consequences. The hypotheses may at first be no more correct than the ones we are using in our intuitive thinking. But the process of computer modeling and model testing requires that these hypotheses be stated more explicitly. The model comes out of the unclear realm of the mental model into an ambiguous model or statement to which all have access. Assumptions can then be checked against all available information and can be readily improved. The great uncertainty with mental models is the inability to anticipate the consequences of interactions between the parts of a system. This uncertainty is totally eliminated in computer models. Given a stated set of assumptions, the computer traces the resulting consequences without doubt or error. This is a powerful procedure for clarifying issues, though it is not easy and its results are not immediate.

However, the field of world modeling is still a very long way from the point of providing efficient and effective policy analysis tools which will be of practical use to policy makers. Little progress has yet been made in resolving the difficult methodological issues raised by the early world modeling projects. Rather, there has been a much greater acceptance of how difficult those issues really are. There has, for the most part, been no stable and continuing base of support for world modeling activities. Therefore, it has been difficult to examine the consequences and implications of the early efforts. As a result of this fluctuating support, a particular problem has been the absence of comparability among models and a failure to undertake rigorous analysis which could increase the confidence of potential users in model results.

There are certain criteria world models must meet in order to be both useful and technically feasible. Models can be tested as to truthfulness and accuracy of representation only as they can be used to affect action. World models which allow us to forecast the future do so either (1) as a projection of what will occur if all present policies are continued into the future or (2) as a projection of the alteration of some present policy. As co-producers of our own future, it behooves us to make use of world models.

World models should explicitly display our actions as producer relations in the model. Econometric models fail to do this to some degree but with commitment to aggregation that limits their usefulness to actual planning decisions or testability of their accuracy in representation. World models should display the relation of concrete human acts upon the world and upon a regionalized basis so that the impact of actual acts can be studied. Planning consists of designing and implementing desired futures for humankind through participative procedures. Models must be useful to this process if they are to be valid. In order to be of use in the planning world a program of model construction should have the following requirements (Betz & Azevedo, 1976):

> 1. the models be descriptive of structural details of the world (utilizing the best technology of observation, e.g., satellite techniques);
> 2. the models be developed for actual planning situations and thus be at least as regionalized as there exist governmental authorities or industrial firms to take action upon information which the models provide;
> 3. that the regionalized models are connectable into a world model (e.g., organized into a connected computer network);
> 4. the models be explicitly constructed in producer or causal relations and the distinctions maintained in the potential use of information from the model;
> 5. the models explicitly express the errors on inferred variables as a function of the errors on observed data. (pp. 42-43)

Implications of World Modeling for National Planning

In applying world models in the planning areas of public life institutional-design problems will arise. In terms of data collection, national governments must organize or reorganize agencies to collect data and model the world on a regionalized basis. An international agency should coordinate these national efforts so that common information can be exchanged between governments. Information will have military, economic, and political implications. Protocols will have to be set up as to what information is exchangeable between nations and in what form.

Because of the complex nature of integrated societal planning, which requires a multidisciplinary as well as a multi- (government-)

departmental approach, certain institutional innovations would be highly desirable. These include the creation of a national goals institute and of a technology assessment center. The former would identify alternative sets of national priorities that are both feasible in view of existing resource limitations and responsive to reasonable demands. The latter would have the task of anticipating important future technological developments, forecasting their societal implications, and recommending appropriate research strategies, legislation, or regulative measure.

An international agency should take responsibility for the development of regionalized and cooperating networks of modeling and planning efforts. Such an international group would be organized on neutral grounds rather than under government auspices. Governments, of course, must be active participants, but as partners not leaders. Required, therefore, at least in the beginning, is a new type of private nonprofit anticipatory institution operating at the world level with a representative membership of public and private decisionmakers. The institution should not be a research organization; it should be a relay station, using the best techniques of information technology to develop among its membership a common awareness of prospects and problems.

On the level of national planning and decision-making, world models can provide valuable insight into the effects of various policies on the rest of the world. Forecasts from world models would allow nations to examine their possible futures and to make changes now to avoid any possible crises. This would be particularly helpful for the nation-states of South Asia and Africa as they face drastic changes in the future. There are also implications for city planning as well. Whereas, world modeling may not be useful in the average city, it can provide valuable information for "international cities" (e.g., New York, New York) and cities targeted for substantial growth in the future (such as those in South Asia and Africa). World modeling forecasts can provide them with information needed for careful and effective long-range planning on both the national and city levels.

Along with the institution of these agencies, there ought to be a change in the outlook of education and corporate policy on world modeling. Most of social science literature and education is confined within a few very narrow channels that even together fail to cover the issues or meet the needs of the times. There should be more investigation of the underlying principles, concepts, and philosophy of modeling. Such emphasis on fundamentals could well be at the expense of still more data gathering and model construction until issues of procedure and relevance have become clearer. In particular, there ought to be a change in university graduate school curriculum, placing greater emphasis on interdisciplinary cooperation and on an appreciation of the mutual cross-disciplinary effects of societal development.

In the corporate realm, the larger multinational corporations represent concentrations of power that rival those of weaker nations. This power brings with it responsibility. A large portion of the world's research and development budget is controlled by multinational corporations. These corporations can bring their impressive research and development capacity to bear on the ability of the world to make a transition from growth to equilibrium. In the meantime, as a starting point, multinational corporations can help in the development of renewable energy sources and so create a more energy-efficient economy by improving the energy efficiency of their own operations.

Planners are also finding an important place in the corporate realm. It will be even more crucial that their education include the necessary curriculum mentioned above in order that they may better assist the multinational corporations in their abilities to help lead the world toward equilibrium. better assist the multinational corporations in their abilities to help lead the world toward equilibrium.

CHAPTER 7

SUMMARY

While world modeling is not a new practice, its assimilation into the planning field represents a rather new idea. It is an idea whose time has come. As this study has attempted to illustrate, the world problematique is a growing concern, and its solutions are neither simple nor concise. They are, in fact, as complex as the problems found in the world system. This study has also attempted to show that the complexity of the possible solutions is no reason to ignore the problems or let present undesirable trends continue unabated. The world has continued on a trend of accelerating growth, and the time has come for a new direction toward equilibrium. Planners, by nature of their profession, can and must play a part in affecting this change in direction to one toward equilibrium.

In examining the ways in which the world can make such a drastic change in its patterns, world models can play a crucial role. In order to understand that role a basic knowledge of world models is necessary. To that effect, this study has outlined three various world models using three different methodologies. All of these models view the world from a slightly different view point based on the modelers' original purpose for their being developed. The models illustrated in this study were World2 and World3 developed by Jay Forrester and Dennis Meadows, the World Integrated Model originated by Mihajlo Mesarovic and Eduard Pestel, and the United Nations Model developed by Wassily Leontief.

Chapter 2 outlined the World2 and World3 models in some detail. These models were developed using system dynamics theory, and therefore, view the world from a slightly different perspective than the other two models. Chapter 3 outlined the World Integrated Model which was developed using a hierarchical systems approach. This methodology viewed the world in a complex of five interrated planes. Chapter 4 examined the United Nations world model. This model was developed using an input-output approach. This varies greatly from the methodologies of the first two models examined. It, along with the other two models, is intended to illustrate the wide variety of approaches available in modeling the world system.

Despite the variety available, the study does not attempt to choose the best world model. There are limitations to all three models as well as to world modeling in general. These limitations are outlined in Chapter 5 along with an assessment of the results of the "basic runs" of the three aforementioned models. It is pointed out in this chapter that the model user must determine from which direction he/she wishes to view the world before the selection of a model may be chosen. Chapter 5 also outlines the aspects of world modeling and the use of world models of which both worlds modelers and users need to be aware.

Chapter 6 looked at the role of world modeling in the planning profession. The study illuminates the idea that planners, by profession, can and need to be aware of the world problematique and planning for its solution. It is obvious that the present trend of accelerating growth cannot be continued forever. What is not obvious, however, is the way to change this growth pattern. Planners are trained to view social systems in rather holistic terms. It is just this type of outlook that is needed in examining the world system. World models fit in the planning process by providing a simulation technique for examining the effects of various policy actions on the future of the various sectors of the world system. Modeling can be used as a valuable tool as long as the user is conscious of its limitations and the assumptions used in running the model and analyzing its results. World models alone cannot provide the answers to the world problematique. It will take a careful marriage of planning, policy-making, and implementation in conjunction with the use of world models to effect the world's present pattern of growth.

The planning profession is not the only place in which world models need to be introduced. Both the educational and corporate realms of our society would benefit from the use and study of world models, resulting in their contribution to changing the world's pattern of accelerating growth. Chapter 6 discusses the role of world models in both of these areas of study. Both the educational and corporate areas of society have a large impact on our world and can go a long way to urging the world to change its direction toward one of equilibrium.

While this study has discussed world models and their place in the planning field, there are many other aspects of the topic that are in need of further examination. Perhaps most importantly, there is need for a concrete proposal for the collection of world-wide data. This data can probably be collected most efficiently at the national and regional levels and then compiled in world-wide form. This would suggest the formation of a clearinghouse to gather the information and see that it is collected and formulated on a uniform basis. This task is, in and of itself, an enormous challenge and one which cannot be taken lightly. However, if this could be accomplished this data could be shared, making the development of future world models much more uniform, resulting in the ability to compare and contrast their structure and results in a much more effective and efficient manner.

Another area for future study is that of prescriptions for the use of world models in aiding in the formation of policy decisions. Nations and countries must consider more than themselves in making policy decisions. What they decide politically often effects other areas of the world in addition to their own countries. A technique needs to be discovered, however, in which policymakers are made confident and sure of the role modeling can play in their profession. An educational process needs to take place in which policymakers are introduced to and shown the possibilities that world modeling has to offer. Likewise, model builders need to be made aware of the needs of policymakers in order to develop more effective world models. The cost of the use of world models will continue to be a stumbling block to this process until the practice of data collection can be brought to the level discussed above.

One final area of study is found in the problem of convincing the world population to think and act in a global manner. The attempt to change the world's pattern from growth to equilibrium cannot be done overnight. The value systems and thought patterns of the various races of our planet will need to be altered. This, in and of itself, will take a long period of time and a massive change in our present practices of education. Our future has always depended on the next generation and it is with these young minds that the change to a global outlook must begin. Suggestions for changes in thought patterns in educational, religious, familial, and other institutional areas of life are needed.

It is hoped that this study has provided a background of knowledge on world modeling and suggestions for its use in the planning areas of our social system. The field of world modeling is by no means complete and is in need of much further study in various areas of interest. It is an important tool, however, for viewing the world and the effects of policy decisions on its various interconnected systems. What world models have to offer in terms of analyzing a extremely complex world system cannot be ignored. A constant reviewing and updating process is necessary for existing models along with the development of new and better world models. The world problematique is too important to ignore, and world modeling offers a coherent way in which to observe its patterns and the effects of proposed policy decisions.

LIST OF REFERENCES

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Brown, Lester R. (1981). Building a sustainable society. New York: W. W. Norton and Co.

Bruton, M. J. (Ed.) (1974). The spirit and purpose of planning. London: Hutchinson and Co.

Churchman, C. W. (1976). The niggling and the grand. In Martin K. Starr, C. West Churchman, & Richard O. Mason (Eds.), World modeling: A dialogue (pp. 159-163). Amsterdam: North-Holland Publishing,

Cole, H. S. D., Freeman, Christopher, Jahoda, Marie, & Pravitt, K. L. R. (1973). Models of doom. New York: Universe Books.

Cole, Sam. (1977). Global models and the international economic order. Oxford: Pergamon Press.

Coomer, James C. (Ed.) (1981). Quest for a sustainable society. Oxford: Pergamon Press.

Council on Environmental Quality and the Department of State. (1980). The global 2000 report to the president: The technical report. Vol. II. Washington, D.C.: U.S. Government Printing Office.

Dayal, Ram. (1981). An integrated system of world models. Amsterdam: North-Holland Publishing.

Forrester, Jay W. (1973). Churches at the transition between growth and world equilibrium. In Dennis L. Meadows, & Donella H. Meadows, (Eds.), Toward global equilibrium: Collected papers (pp. 3-30). Cambridge, Massachusetts: Wright-Allen Press.

________. (1973). Counterintuitive behavior of social systems. In Dennis L. Meadows, & Donella H. Meadows, (Eds.), Toward global equilibrium: Collected papers (pp. 54-62). Cambridge, Massachusetts: Wright-Allen Press.

________. (1976). Educational implications of responses to system dynamics models. In Martin K. Starr, C. West Churchman, & Richard O. Mason (Eds.), World modeling: A dialogue (pp. 27-34). Amsterdam: North-Holland Publishing.

________. (1961). Industrial dynamics. Cambridge, Massachusetts: Massachusetts Institute Technology Press.

________. (1968). Principles of systems. Cambridge, Massachusetts: Wright-Allen Press.

_______. (1971). World dynamics. Cambridge, Massachusetts: Wright-Allen Press.

Fuller, R. Buckminster. (1973). Earth, inc. New York: Anchor Press.

Heilbroner, Robert L. (1980). An inquiry into the human prospect. New York: W. W. Norton and Co.

Helmer, Olaf. (1983). Looking forward. Beverly Hills, California: Sage Publications.

Higgins, Benjamin, & Higgins, Jean Downing. (1979). Economic development of a small planet. New York: W. W. Norton and Co.

House, Peter W. & McLeod, John. (1977). Large-scale models for policy evaluation. New York: John Wiley and Sons.

Hughes, Barry B. (1980). World modeling. Lexington, Massachusetts: Lexington Books.

Intriligator, Michael D. (1978). Econometric models, techniques, and applications. Englewood Cliffs, New Jersey: Prentice-Hall.

Javits, Jacob. (1977). In defense of long-range federal planning. In Dennis L. Meadows (Ed.), Alternatives to growth--I: A search for sustainable futures (pp. 195-202). Cambridge, Massachusetts: Ballinger Publishing.

LaMontagne, Maurice. (1977). The pitfalls of national planning. In Dennis L. Meadows (Ed.), Alternatives to growth--I: A search for sustainable futures (pp. 203-216). Cambridge, Massachusetts: Ballinger Publishing.

Laszlo, Ervin & Bierman, Judah. (Eds.) (1977). Goals in a global community. Oxford: Pergamon Press.

Laszlo, Ervin et al., (1977). Goals for mankind. New York: E. P. Dutton and Co.

Legasto, Augusto A., Jr., Forrester, Jay W., & Lyneis, James M. (Eds.) (1980). System dynamics. Amsterdam: North-Holland Publishing.

Leontief, Wassily et al., (1977) The future of the world economy. New York: Oxford University Press.

Leontief, Wassily. (1977). Structure of the world economy: Outline of a simple input-output formulation. (Nobel Memorial Lecture). In American Economic Review, December.

Loraine, John A. (1979). Global signposts to the 21st century. Seattle: University of Washington Press.

Meadows, Dennis et al. (1974). Dynamics of growth in a finite world. Cambridge, Massachusetts: Wright-Allen Press.

Meadows, Donella H., Meadows, Dennis L., Randers, Jorgan, & Behrens, William K., III. (1972). Limits to growth. New York: Universe Books.

Mesarovic, M., & Pestel, Eduard. (1974). Mankind at the turning point. New York: E. P. Dutton and Co.

Miernyk, William H. (1965). The elements of input-output analysis. New York: Random House.

Peccei, Aurelio. (1977). The human quality. Oxford: Pergamon Press.

Richardson, Harry W. (1972). Input-output and regional economics. New York: John Wiley and Sons.

Richardson, John M,. Jr. (1978). Global modeling: A survey and appraisal. In Institute for Environmental Studies--University of Wisconsin--Madison (Ed.), Proceedings of the Wisconsin Seminar on Natural Resource Policies in Relation to Economic Development and International Cooperation (pp. 133-188). Madison, Wisconsin: University of Wisconsin-Madison Press.

Rothkopf, Michael H. (1976). Limits to models. In Martin K. Starr, C. West Churchman, & Richard O. Mason (Eds.), World modeling: A dialogue (pp. 155-157). Amsterdam: North-Holland Publishing.

Sagan, Carl. (1985, February 3). The warming of the world. The Knoxville News-Sentinel, pp. 9-11.

Servan-Schreiber, Jean-Jacques (1980). The world challenge. New York: Simon and Schuster.

Starr, Martin K. (1976). The logistics of size. In Martin K. Starr, C. West Churchman, & Richard O. Mason (Eds.), World modeling: A dialogue (pp. 117-127). Amsterdam: North-Holland Publishing.

APPENDICES

APPENDIX A

DEFINITION OF DYNAMO FLOW DIAGRAM EQUATIONS

NAME	NO*	T**	DEFINITION
AHL	146	A	ASSIMILATION HALF-LIFE (YEARS)
AHLM	145	A	ASSIMILATION HALF-LIFE MULTIPLIER (DIMENSIONLESS)
AHLMT	145.1	T	AHLM TABLE
AHL70	146.1	C	ASSIMILATION HALF-LIFE IN 1970 (YEARS)
AI	99	A	AGRICULTURAL INPUTS (DOLLARS/YEAR)
	99.1	N	
AIOPC	43	A	AVERAGE INDUSTRIAL OUTPUT PER CAPITA (DOLLARS/PERSON-YEAR)
AIPH	101	A	AGRICULTURAL INPUTS PER HECTARE (DOLLARS/ HECTARE-YEAR)
AL	85	L	ARABLE LAND (HECTARES)
	85.1	N	
ALAI	100	A	AVERAGE LIFETIME OF AGRICULTURAL INPUTS (YEARS)
ALAI1	100.1	C	ALAI, VALUE BEFORE TIME=PYEAR (YEARS)
ALAI2	100.2	C	ALAI, VALUE AFTER TIME=PYEAR (YEARS)
ALI	85.2	C	ARABLE LAND INITIAL (HECTARES)
ALIC	54	A	AVERAGE LIFETIME OF INDUSTRIAL CAPITAL (YEARS)
ALIC1	54.1	C	ALIC, VALUE BEFORE TIME=PYEAR (YEARS)
ALIC2	54.2	C	ALIC, VALUE AFTER TIME=PYEAR (YEARS)
ALL	112	A	AVERAGE LIFE OF LAND (YEARS)
ALLN	112.1	C	AVERAGE LIFE OF LAND NORMAL (YEARS)
ALPHA			PERCENTAGE GROWTH PER YEAR (1/YEAR)
ALSC	69	A	AVERAGE LIFETIME OF SERVICE CAPITAL (YEARS)
ALSC1	69.1	C	ALSC, VALUE BEFORE TIME=PYEAR (YEARS)
ALSC2	69.2	C	ALSC, VALUE AFTER TIME=PYEAR (YEARS)
AMTI	140.2	C	AGRICULTURAL MATERIALS TOXICITY INDEX (POLLUTION UNITS/DOLLAR)
B	30	R	BIRTHS PER YEAR (PERSONS/YEAR)
CAI	98	A	CURRENT AGRICULTURAL INPUTS (DOLLARS/YEAR)
CBR	31	S	CRUDE BIRTH RATE (BIRTHS/1000 PERSON-YEARS)
CDR	18	S	CRUDE DEATH RATE (DEATHS/1000 PERSON-YEARS)
CLIP			A FUNCTION SWITCHED DURING THE RUN
CMI	27	A	CROWDING MULTIPLIER FROM INDUSTRIALIZATION (DIMENSIONLESS)
CMIT	27.1	T	CMI TABLE
CMPLE	36	A	COMPENSATORY MULTIPLIER FROM PERCEIVED LIFE EXPECTANCY (DIMENSIONLESS)
CMPLET	36.1	T	CMPLE TABLE
COPM			CAPITAL OUTPUT PRICE MULTIPLIER (DIMENSIONLESS)
COPMT			COPM TABLE
COYM			CAPITAL OUTPUT YIELD MULTIPLIER (DIMENSIONLESS)
COYMT			COYM TABLE

CUF	83	A	CAPITAL UTILIZATION FRACTION
	83.1	N	(DIMENSIONLESS)
CUFT	83.2	T	CUF TABLE
D	17	A	DEATHS PER YEAR (PERSONS/YEAR)
DCFS	38	A	DESIRED COMPLETED FAMILY SIZE (DIMENSIONLESS)
DCFSN	38.2	C	DESIRED COMPLETED FAMILY SIZE NORMAL (DIMENSIONLESS)
DCPH	97	A	DEVELOPMENT COST PER HECTARE (DOLLARS/ HECTARE)
DCPHT	97.1	T	DCPH TABLE
DELAY3			THIRD-ORDER EXPONENTIAL MATERIAL DELAY
DIOPC	40	A	DELAYED INDUSTRIAL OUTPUT PER CAPITA (DOLLARS/PERSON-YEAR)
DLINF3			THIRD-ORDER EXPONENTIAL INFORMATION DELAY
DNRUR			DESIRED NONRENEWABLE RESOURCE USAGE RATE (RESOURCE UNITS/YEAR)
DPOLX			ACCEPTABLE POLLUTION LEVEL (DIMENSIONLESS)
DT			TIME INTERVAL BETWEEN CONSECUTIVE CALCULATIONS (YEARS)
DTF	35	A	DESIRED TOTAL FERTILITY (DIMENSIONLESS)
D1	3	R	DEATHS PER YEAR, AGES 0-14 (PERSONS/YEAR)
D2	7	R	DEATHS PER YEAR, AGES 15-44 (PERSONS/YEAR)
D3	11	R	DEATHS PER YEAR, AGES 45-64 (PERSONS/YEAR)
D4	15	R	DEATHS PER YEAR, AGES 65+ (PERSONS/YEAR)
EHSPC	22	A	EFFECTIVE HEALTH SERVICES PER CAPITA (DOLLARS/PERSON-YEAR)
EXPON			EXPONENTIAL GROWTH RATE FROM TECHNOLOGY (1/ YEAR)
F	87	A	FOOD (VEGETABLE-EQUIVALENT KILOGRAMS/YEAR)
FALM	126	A	FRACTION OF INPUTS ALLOCATED TO LAND MAINTENANCE (DIMENSIONLESS)
FALMT	126.1	T	FALM TABLE
FCAOR	134	A	FRACTION OF CAPITAL ALLOCATED TO OBTAINING RESOURCES (DIMENSIONLESS)
FCAOR1	135	A	FCAOR, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
FCAOR1T	135.1	T	FCAOR1 TABLE
FCAOR2	136	A	FCAOR, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
FCAOR2T	136.1	T	FCAOR2 TABLE
FCAPC	47	A	FERTILITY CONTROL ALLOCATIONS PER CAPITA (DOLLARS/PERSON-YEAR)
FCE	45	A	FERTILITY CONTROL EFFECTIVENESS (DIMENSIONLESS)
FCEST	45.1	C	FERTILITY CONTROL EFFECTIVENESS SET TIME (YEAR)
FCET	45.2	T	FCE TABLE
FCFPC	46	A	FERTILITY CONTROL FACILITIES PER CAPITA (DOLLARS/PERSON-YEAR)
FIALD	108	A	FRACTION OF INPUTS ALLOCATED TO LAND DEVELOPMENT (DIMENSIONLESS)
FIALDT	108.1	T	FIALD TABLE
FIE	42	A	FAMILY INCOME EXPECTATION (DIMENSIONLESS)
FIOAA	93	A	FRACTION OF INDUSTRIAL OUTPUT ALLOCATED TO AGRICULTURE (DIMENSIONLESS)
FIOAA1	94	A	FIOAA, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
FIOAA1T	94.1	T	FIOAA1 TABLE
FIOAA2	95	A	FIOAA, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
FIOAA2T	95.1	T	FIOAA2 TABLE
FIOAC	57	A	FRACTION OF INDUSTRIAL OUTPUT ALLOCATED TO CONSUMPTION (DIMENSIONLESS)
FIOACC	58	A	FIOAC CONSTANT (DIMENSIONLESS)
FIOACV	59	A	FIOAC VARIABLE (DIMENSIONLESS)
FIOACVT	59.1	T	FIOACV TABLE
FIOAC1	58.1	C	FIOAC, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
FIOAC2	58.2	C	FIOAC, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
FIOAI	56	A	FRACTION OF INDUSTRIAL OUTPUT ALLOCATED TO INDUSTRY (DIMENSIONLESS)
FIOAS	63	A	FRACTION OF INDUSTRIAL OUTPUT ALLOCATED TO SERVICES (DIMENSIONLESS)
FIOAS1	64	A	FIOAS, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
FIOAS1T	64.1	T	FIOAS1 TABLE
FIOAS2	65	A	FIOAS, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)

FIOAS2T	65.1	T	FIOAS2 TABLE
FIPM	140.1	C	FRACTION OF INPUTS AS PERSISTENT MATERIALS (DIMENSIONLESS)
FM	34	A	FECUNDITY MULTIPLIER (DIMENSIONLESS)
FMT	34.1	T	FM TABLE
FOA	147	S	FRACTION OF OUTPUT IN AGRICULTURE (DIMENSIONLESS)
FOI	148	S	FRACTION OF OUTPUT IN INDUSTRY (DIMENSIONLESS)
FOS	149	S	FRACTION OF OUTPUT IN SERVICES (DIMENSIONLESS)
FPC	88	A	FOOD PER CAPITA (VEGETABLE-EQUIVALENT KILOGRAMS/PERSON-YEAR)
FPU	26	A	FRACTION OF POPULATION URBAN (DIMENSIONLESS)
FPUT	26.1	T	FPU TABLE
FR	127	A	FOOD RATIO (DIMENSIONLESS)
FRPM	139.1	C	FRACTION OF RESOURCES AS PERSISTENT MATERIALS (DIMENSIONLESS)
FRSN	41	A	FAMILY RESPONSE TO SOCIAL NORM
	41.2	N	(DIMENSIONLESS)
FRSNT	41.1	T	FRSN TABLE
FSAFC	48	A	FRACTION OF SERVICES ALLOCATED TO FERTILITY CONTROL (DIMENSIONLESS)
FSAFCT	48.1	T	FSAFC TABLE
FSPD	128.2	C	FOOD SHORTAGE PERCEPTION DELAY (YEARS)
HSAPC	21	A	HEALTH SERVICES ALLOCATIONS PER CAPITA (DOLLARS/PERSON-YEAR)
HSAPCT	21.1	T	HSAPC TABLE
HSID	22.1	C	HEALTH SERVICES IMPACT DELAY (YEARS)
IC	52	L	INDUSTRIAL CAPITAL (DOLLARS)
	52.1	N	
ICDR	53	R	INDUSTRIAL CAPITAL DEPRECIATION RATE (DOLLARS/YEAR)
ICI	52.2	C	INDUSTRIAL CAPITAL INITIAL (DOLLARS)
ICIR	55	R	INDUSTRIAL CAPITAL INVESTMENT RATE (DOLLARS/YEAR)
ICOR	51	A	INDUSTRIAL CAPITAL-OUTPUT RATIO (YEARS)
ICOR1	51.1	C	ICOR, VALUE BEFORE TIME=PYEAR (YEARS)
ICOR2	51.2	C	ICOR, VALUE AFTER TIME=PYEAR (YEARS)
ICOR2T			CAPITAL OUTPUT TABLE FROM RESOURCES
IEAT	43.1	C	INCOME EXPECTATION AVERAGING TIME (YEARS)
IET	57.1	C	INDUSTRIAL EQUILIBRIUM TIME (YEAR)
IFPC	89	A	INDICATED FOOD PER CAPITA (VEGETABLE-EQUIVALENT KILOGRAMS/PERSON-YEAR)
IFPC1	90	A	IFPC, VALUE BEFORE TIME=PYEAR (VEGETABLE-EQUIVALENT KILOGRAMS/PERSON-YEAR)
IFPC1T	90.1	T	IFPC1 TABLE
IFPC2	91	A	IFPC, VALUE AFTER TIME=PYEAR (VEGETABLE-EQUIVALENT KILOGRAMS/PERSON-YEAR)
IFPC2T	91.1	T	IFPC2 TABLE
ILF	124.1	C	INHERENT LAND FERTILITY (VEGETABLE-EQUIVALENT KILOGRAMS/HECTARE-YEAR)
IMEF	139.2	C	INDUSTRIAL MATERIALS EMISSION FACTOR (DIMENSIONLESS)
IMTI	139.3	C	INDUSTRIAL MATERIALS TOXICITY INDEX (POLLUTION UNITS/RESOURCE UNIT)
IO	50	A	INDUSTRIAL OUTPUT (DOLLARS/YEAR)
IOPC	49	A	INDUSTRIAL OUTPUT PER CAPITA (DOLLARS/PERSON-YEAR)
IOPCD	59.2	C	INDUSTRIAL OUTPUT PER CAPITA DESIRED (DOLLARS/PERSON-YEAR)
IO70	107.2	C	INDUSTRIAL OUTPUT IN 1970 (DOLLARS/YEAR)
ISOPC	60	A	INDICATED SERVICE OUTPUT PER CAPITA (DOLLARS/PERSON-YEAR)
ISOPC1	61	A	ISOPC, VALUE BEFORE TIME=PYEAR (DOLLARS/PERSON-YEAR)
ISOPC1T	61.1	T	ISOPC1 TABLE
ISOPC2	62	A	ISOPC, VALUE AFTER TIME=PYEAR (DOLLARS/PERSON-YEAR)
ISOPC2T	62.1	T	ISOPC2 TABLE
J	73	A	JOBS (PERSONS)
JPH	79	A	JOBS PER HECTARE (PERSONS/HECTARE)
JPHT	79.1	T	JPH TABLE
JPICU	75	A	JOBS PER INDUSTRIAL CAPITAL UNIT (PERSONS/DOLLAR)
JPICUT	75.1	T	JPICU TABLE
JPSCU	77	A	JOBS PER SERVICE CAPITAL UNIT (PERSONS/DOLLAR)

JPSCUT	77.1	T	JPSCU TABLE
LDR	96	R	LAND DEVELOPMENT RATE (HECTARES/YEAR)
LE	19	A	LIFE EXPECTANCY (YEARS)
LEN	19.1	C	LIFE EXPECTANCY NORMAL (YEARS)
LENGTH			LENGTH OF THE SIMULATION RUN (YEARS)
LER	116	R	LAND EROSION RATE (HECTARES/YEAR)
LF	80	A	LABOR FORCE (PERSONS)
LFC	84	A	LAND FRACTION CULTIVATED (DIMENSIONLESS)
LFD	123	R	LAND FERTILITY DEGRADATION (VEGETABLE-EQUIVALENT KILOGRAMS/HECTARE-YEAR-YEAR)
LFDR	122	A	LAND FERTILITY DEGRADATION RATE (1/YEAR)
LFDRT	122.1	T	LFDR TABLE
LFERT	121	L	LAND FERTILITY (VEGETABLE-EQUIVALENT
	121.1	N	KILOGRAMS/HECTARE-YEAR)
LFERTI	121.2	C	LAND FERTILITY INITIAL (VEGETABLE-EQUIVALENT KILOGRAMS/HECTARE-YEAR)
LFH	87.1	C	LAND FRACTION HARVESTED (DIMENSIONLESS)
LFPF	80.1	C	LABOR FORCE PARTICIPATION FRACTION (DIMENSIONLESS)
LFR	124	R	LAND FERTILITY REGENERATION (VEGETABLE-EQUIVALENT KILOGRAMS/HECTARE-YEAR-YEAR)
LFRT	125	A	LAND FERTILITY REGENERATION TIME (YEARS)
LFRTT	125.1	T	LFRT TABLE
LLMY	113	A	LAND LIFE MULTIPLIER FROM YIELD (DIMENSIONLESS)
LLMY1	114	A	LLMY, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
LLMY1T	114.1	T	LLMY1 TABLE
LLMY2	115	A	LLMY, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
LLMY2T	115.1	T	LLMY2 TABLE
LMC	28	A	LIFETIME MULTIPLIER FROM CROWDING (DIMENSIONLESS)
LMF	20	A	LIFETIME MULTIPLIER FROM FOOD (DIMENSIONLESS)
LMFT	20.1	T	LMF TABLE
LMHS	23	A	LIFETIME MULTIPLIER FROM HEALTH SERVICES (DIMENSIONLESS)
LMHS1	24	A	LMHS, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
LMHS1T	24.1	T	LMHS1 TABLE
LMHS2	25	A	LMHS, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
LMHS2T	25.1	T	LMHS2 TABLE
LMP	29	A	LIFETIME MULTIPLIER FROM PERSISTENT POLLUTION (DIMENSIONLESS)
LMPT	29.1	T	LMP TABLE
LOGN			NATURAL LOGARITHM
LPD	37.1	C	LIFETIME PERCEPTION DELAY (YEARS)
LRUI	119	R	LAND REMOVAL FOR URBAN-INDUSTRIAL USE (HECTARES/YEAR)
LUF	81	A	LABOR UTILIZATION FRACTION (DIMENSIONLESS)
LUFD	82	A	LABOR UTILIZATION FRACTION DELAYED (DIMENSIONLESS)
LUFDT	82.1	C	LABOR UTILIZATION FRACTION DELAY TIME (YEARS)
LY	103	A	LAND YIELD (VEGETABLE-EQUIVALENT KILOGRAMS/HECTARE-YEAR)
LYCM			LAND YIELD TECHNOLOGY CHANGE MULTIPLIER (1/YEAR)
LYCMT			LYCM TABLE
LYF	104	A	LAND YIELD FACTOR (DIMENSIONLESS)
LYF1	104.1	C	LYF, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
LYF2	104.2	C	LYF, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
LYF2R			LAND YIELD TECHNOLOGY IMPROVEMENT RATE (1/YEAR)
LYMAP	105	A	LAND YIELD MULTIPLIER FROM AIR POLLUTION (DIMENSIONLESS)
LYMAP1	106	A	LYMAP, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
LYMAP1T	106.1	T	LYMAP1 TABLE
LYMAP2	107	A	LYMAP, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
LYMAP2T	107.1	T	LYMAP2 TABLE
LYMC	102	A	LAND YIELD MULTIPLIER FROM CAPITAL (DIMENSIONLESS)
LYMCT	102.1	T	LYMC TABLE
LYTD			LAND YIELD TECHNOLOGY INITIATED (1/YEAR)

MAT1	5	R	MATURATION RATE, AGE 14-15 (PERSONS/YEAR)
MAT2	9	R	MATURATION RATE, AGE 44-45 (PERSONS/YEAR)
MAT3	13	R	MATURATION RATE, AGE 64-65 (PERSONS/YEAR)
MIN			MINIMUM VALUE FUNCTION
MLYMC	111	A	MARGINAL LAND YIELD MULTIPLIER FROM CAPITAL (HECTARES/DOLLAR)
MLYMCT	111.1	T	MLYMC TABLE
MPAI	110	A	MARGINAL PRODUCTIVITY OF AGRICULTURAL INPUTS (VEGETABLE EQUIVALENT KILOGRAMS/ DOLLAR)
MPLD	109	A	MARGINAL PRODUCTIVITY OF LAND DEVELOPMENT (VEGETABLE-EQUIVALENT KILOGRAMS/DOLLAR)
MTF	33	A	MAXIMUM TOTAL FERTILITY (DIMENSIONLESS)
MTFN	33.1	C	MAXIMUM TOTAL FERTILITY NORMAL (DIMENSIONLESS)
M1	4	A	MORTALITY, AGES 0-14 (DEATHS/PERSON-YEAR)
M1T	4.1	T	M1 TABLE
M2	8	A	MORTALITY, AGES 15-44 (DEATHS/PERSON-YEAR)
M2T	8.1	T	M2 TABLE
M3	12	A	MORTALITY, AGES 45-64 (DEATHS/PERSON-YEAR)
M3T	12.1	T	M3 TABLE
M4	16	A	MORTALITY, AGES 65+ (DEATHS/PERSON-YEAR)
M4T	16.1	T	M4 TABLE
NFC	44	A	NEED FOR FERTILITY CONTROL (DIMENSIONLESS)
NR	129	L	NONRENEWABLE RESOURCES (RESOURCE UNITS)
	129.1	N	
NRATE			RESOURCE TECHNOLOGY IMPROVEMENT RATE (1/ YEAR)
NRCM			RESOURCE TECHNOLOGICAL CHANGE MULTIPLIER (1/YEAR)
NRCMT			NRCM TABLE
NRFR	133	A	NONRENEWABLE RESOURCE FRACTION REMAINING (DIMENSIONLESS)
NRI	129.2	C	NONRENEWABLE RESOURCES INITIAL (RESOURCE UNITS)
NRTD			NONRENEWABLE RESOURCE TECHNOLOGY INITIATED (1/YEAR)
NRUF	131	A	NONRENEWABLE RESOURCE USAGE FACTOR (DIMENSIONLESS)
NRUF1	131.1	C	NRUF, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
NRUF2	131.2	C	NRUF, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
NRUR	130	R	NONRENEWABLE RESOURCE USAGE RATE (RESOURCE UNITS/YEAR)
PAL	86	L	POTENTIALLY ARABLE LAND (HECTARES)
	86.1	N	
PALI	86.2	C	POTENTIALLY ARABLE LAND INITIAL (HECTARES)
PALT	84.1	C	POTENTIALLY ARABLE LAND TOTAL (HECTARES)
PCRUM	132	A	PER CAPITA RESOURCE USAGE MULTIPLIER (RESOURCE UNITS/PERSON-YEAR)
PCRUMT	132.1	T	PCRUM TABLE
PET	30.2	C	POPULATION EQUILIBRIUM TIME (YEAR)
PFR	128	A	PERCEIVED FOOD RATIO (DIMENSIONLESS)
	128.1	N	
PJAS	78	A	POTENTIAL JOBS IN AGRICULTURAL SECTOR (PERSONS)
PJIS	74	A	POTENTIAL JOBS IN INDUSTRIAL SECTOR (PERSONS)
PJSS	76	A	POTENTIAL JOBS IN SERVICE SECTOR (PERSONS)
PL	87.2	C	PROCESSING LOSS (DIMENSIONLESS)
PLE	37	A	PERCEIVED LIFE EXPECTANCY (YEARS)
PLIT	151.2	C	INITIATION OF PLOTTED OUTPUT (YEAR)
PLP	151.1	C	PLOTTING PERIOD (YEARS)
PLTPER	151	A	INTERVAL BETWEEN PLOTTED OUTPUT POINTS (YEARS)
POLGFM			POLLUTION CONTROL TECHNOLOGY CHANGE MULTIPLIER (1/YEAR)
POLGFMT			POLGFM TABLE
POP	1	A	POPULATION (PERSONS)
POP1			FRACTION OF THE POPULATION AGE 0-14 (DIMENSIONLESS)
POP2			FRACTION OF THE POPULATION AGE 15-44 (DIMENSIONLESS)
POP3			FRACTION OF THE POPULATION AGE 45-64 (DIMENSIONLESS)
POP4			FRACTION OF THE POPULATION AGE 65+ (DIMENSIONLESS)

PPAPR	141	R	PERSISTENT POLLUTION APPEARANCE RATE (POLLUTION UNITS/YEAR)
PPASR	144	R	PERSISTENT POLLUTION ASSIMILATION RATE (POLLUTION UNITS/YEAR)
PPGAO	140	A	PERSISTENT POLLUTION GENERATED BY AGRICULTURAL OUTPUT (POLLUTIONUNITS/YEAR)
PPGF	138	A	PERSISTENT POLLUTION GENERATION FACTOR (DIMENSIONLESS)
PPGF1	138.1	C	PPGF, VALUE BEFORE TIME=PYEAR (DIMENSIONLESS)
PPGF2	138.2	C	PPGF, VALUE AFTER TIME=PYEAR (DIMENSIONLESS)
PPGIO	139	A	PERSISTENT POLLUTION GENERATED BY INDUSTRIAL OUTPUT (POLLUTION UNITS/YEAR)
PPGR	137	R	PERSISTENT POLLUTION GENERATION RATE (POLLUTION UNITS/YEAR)
PPOL	142	L	PERSISTENT POLLUTION (POLLUTION UNITS)
	142.1	N	
PPOLX	143	A	INDEX OF PERSISTENT POLLUTION (DIMENSIONLESS)
PPOL70	143.1	C	PERSISTENT POLLUTION IN 1970 (POLLUTION UNITS)
PPTD	141.1	C	PERSISTENT POLLUTION TRANSMISSION DELAY (YEARS)
PRATE			POLLUTION CONTROL TECHNOLOGY IMPROVEMENT RATE (1/YEAR)
PRIT	152.1	C	PRINTED OUTPUT INITIATION TIME (YEAR)
PRP	151.3	C	PRINTING PERIOD (YEARS)
PRTPER	152	A	INTERVAL BETWEEN PRINTED OUTPUT POINTS (YEARS)
PRTT	152.2	C	PRINTED OUTPUT TERMINATION TIME (YEAR)
PTD			POLLUTION CONTROL TECHNOLOGY INITIATED (1/YEAR)
PYEAR	150.1	C	YEAR NEW POLICY IS IMPLEMENTED (YEAR)
P1	2	L	POPULATION, AGES 0-14 (PERSONS)
	2.1	N	
P1I	2.2	C	P1 INITIAL (PERSONS)
P2	6	L	POPULATION, AGES 15-44 (PERSONS)
	6.1	N	
P2I	6.2	C	P2 INITIAL (PERSONS)
P3	10	L	POPULATION, AGES 45-64 (PERSONS)
	10.1	N	
P3I	10.2	C	P3 INITIAL (PERSONS)
P4	14	L	POPULATION, AGES 65+ (PERSONS)
	14.1	N	
P4I	14.2	C	P4 INITIAL (PERSONS)
RLT	30.1	C	REPRODUCTIVE LIFETIME (YEARS)
SAD	40.1	C	SOCIAL ADJUSTMENT DELAY (YEARS)
SC	67	L	SERVICE CAPITAL (DOLLARS)
	67.1	N	
SCDR	68	R	SERVICE CAPITAL DEPRECIATION RATE (DOLLARS/YEAR)
SCI	67.2	C	SERVICE CAPITAL INITIAL (DOLLARS)
SCIR	66	R	SERVICE CAPITAL INVESTMENT RATE (DOLLARS/YEAR)
SCOR	72	A	SERVICE CAPITAL-OUTPUT RATIO (YEARS)
SCOR1	72.1	C	SCOR, VALUE BEFORE TIME=PYEAR (YEAR)
SCOR2	72.2	C	SCOR, VALUE AFTER TIME=PYEAR (YEAR)
SD	109.1	C	SOCIAL DISCOUNT (1/YEAR)
SFPC	127.1	C	SUBSISTENCE FOOD PER CAPITA (VEGETABLE-EQUIVALENT KILOGRAMS/PERSON-YEAR)
SFSN	39	A	SOCIAL FAMILY SIZE NORM (DIMENSIONLESS)
SFSNT	39.1	T	SFSN TABLE
SMOOTH			FIRST-ORDER EXPONENTIAL INFORMATION DELAY
SO	70	A	SERVICE OUTPUT (DOLLARS/YEAR)
SOPC	71	A	SERVICE OUTPUT PER CAPITA (DOLLARS/PERSON-YEAR)
TABHL			A FUNCTION WITH VALUES SPECIFIED BY A TABLE
TABLE			A FUNCTION WITH VALUES SPECIFIED BY A TABLE
TAI	92	A	TOTAL AGRICULTURAL INVESTMENT (DOLLARS/YEAR)
TDD			TECHNOLOGICAL DEVELOPMENT AND IMPLEMENTATION DELAY (YEARS)
TF	32	A	TOTAL FERTILITY (DIMENSIONLESS)
TIME	150.2	N	CURRENT TIME IN THE SIMULATION RUN
UIL	120	L	URBAN-INDUSTRIAL LAND (HECTARES)
	120.1	N	

UILDT	119.1	C	URBAN-INDUSTRIAL LAND DEVELOPMENT TIME (YEARS)
UILI	120.2	C	URBAN-INDUSTRIAL LAND INITIAL (HECTARES)
UILPC	117	A	URBAN-INDUSTRIAL LAND PER CAPITA (HECTARES/PERSON)
UILPCT	117.1	T	UILPC TABLE
UILR	118	A	URBAN-INDUSTRIAL LAND REQUIRED (HECTARES)
ZPGT	38.1	C	TIME WHEN DESIRED FAMILY SIZE EQUALS 2 CHILDREN (YEAR)

*Equation number
**Type of variable

Type of Variable

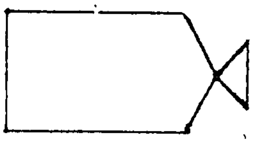
A = Auxiliary Equation
C = Constant
L = Level Equation
N = An Initial Value
R = Rate Equation
S = Supplementary Equation
T = Table

Source: Dynamics of Growth in a Finite World (pp. 587-593) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

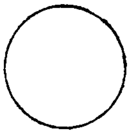
APPENDIX B

DEFINITION OF DYNAMO FLOW DIAGRAM SYMBOLS

= levels; e.g., nonrenewable resources (NR) and industrial capital (IC).

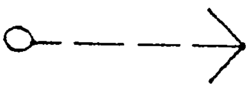


= valves = rates (usage rates)



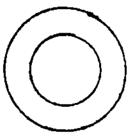
= auxiliaries. Table functions are indicated by overlining and under-lining DYNAMO variable name.

= material flows.



= flows of information.

= input lines representing information inputs from constant parameters.



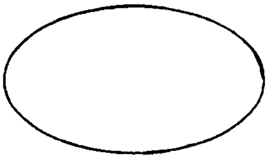
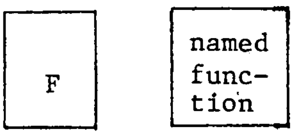
= exogenous, time-dependent input.

= source or sink for various flows. A cloud defines the system boundary. After a flow enters a cloud it no longer affects the system. Similarly what happens to a flow before it enters the system from a cloud is of no importance to the system.

Source: Dynamics of Growth in a Finite World (pp. 595-596) by Dennis L. Meadows et al., 1974, Cambridge, Massachusetts: Wright-Allen Press.

APPENDIX C

DEFINITION OF FLOW DIAGRAM SYMBOLS FOR THE WORLD INTEGRATED MODEL

	=	variables.
	=	functions or subunits with internal dynamics.
+, —, •, ⁒	=	addition, subtraction, multiplication and division mathematicla functions.
	=	mathematical function of greater complexity than the above
————————	=	flow of some material or of individuals through a system; or calculations of material balances.
— — — —	=	causal relationships.

Source: World Modeling (p. 46) by Barry B. Hughes, 1980, Lexington, Massachusetts: D. C. Heath & Co.

APPENDIX D

KEY TO COEFFICIENT SYMBOLS IN PLATE 2

A	Import to output ratios	M	Miscellaneous parameters
B	World export pool shares	P	Prices
C	Consumption coefficients	S	Structure of investment demand
D	Margin trade to physical units	T	Marginal trade composition
E	Emissions coefficients	U	Urban amenities input structure
G	Growth rate type parameters	X	Exogenous data for calibration 1970
K	Capital coefficients	%	Ratio applicable to context
L	Labour coefficients	@	I-A input-output coefficient

Key to units of measurement used for classes of variables

$	1970 dollars for real magnitudes; current dollars for financial magnitudes
MY	man-years
T	metric tons
H	hectares
(B)	billions, i.e. 10^9
(M)	millions, i.e. 10^6
---	diverse physical units applying to individual variables within the general class

Source: Future of the World Economy, by Leontief et al., 1977, New York: Oxford University Press.

APPENDIX E

KEY TO ROWS IN PLATE 2

(Abbreviations for classes of equations)

GDP	1*	Gross domestic product
SAVE	1	Savings equation
INV	1	Investment equation
GOV	1	Government expenditures
IMPRT	1	Total imports
EXPRT	1	Total exports
BAL	1	Balance of payments
LABOR	1	Employment
NUTRN	2	Consumption of food nutrition units
ABDET	5	Abatement determination
EMA	8	Emissions of abatable pollutants
EMNA	8	Emissions of non-abatable pollutants
AGS	4	Selected agricultural commodity balance
AGR	1	Residual agriculture
RSS	9	Selected resource commodity balance
RSR	1	Residual resource commodity balance
AGM	1	Agricultural margins (food)
RSM	2	Resource margins (refining)
XT	19	Output of traded commodities
XNT	6	Output of non-traded commodities
IEQP	1	Equipment investment
IPLT	1	Plant investment
INVCH	1	Inventory change investment equation
ECUMR	9	Cumulative resource output at end of period

SEQP	1	Equipment capital stock
SPLT	1	Plant capital stock
SINVY	1	Inventory stock equation
SFAS	1	Stock of foreign assets
SLAND	1	Cultivated land area
MAGS	4	Imports of selected agriculture
MAGR	1	Imports of residual agriculture
MRSS	9	Imports of selected resources
MRSR	1	Imports of residual resources
MAGM	1	Imports of agricultural margins
MRSM	2	Imports of resource margins
MXT	19	Imports of traded goods
MSER	1	Imports of services
MTR	1	Imports of transport
MAID	1	Aid outflows
EAGS	4	Exports of selected agriculture
EAGR	1	Exports of residual agriculture
ERSS	9	Exports of selected resources
ERSR	1	Exports of residual resources
EAGM	1	Exports of agricultural margins
ERSM	2	Exports of resource margins
EXT	19	Exports of traded goods
ESER	1	Exports of services
ETR	1	Exports of transport
EAID	1	Aid inflow
ECAP	1	Capital inflow
MCAP	1	Capital outflow
DUMMY	2	Dummy equations

* The number following each symbol indicates how many equations of this type are contained in each regional set.

APPENDIX F

KEY TO COLUMNS IN PLATE 2

(Abbreviations for classes of variables)

GDP	1[a]	GDP $ (B)[b]
CONS	1	Consumption level $ (B)
DSAVE	1	Excess savings potential $ (B)
INV	1	Investment level $ (B)
GOV	1	Government expenditures $ (B)
BAL	1	Balance of payments (capital inflow) $ (B)
IMPRT	1	Total imports $ (B)
EXPRT	1	Total exports $ (B)
POP	1	Population (M)
URBAN	1	Urban population (M)
LABOR	1	Employment MY (M)
NUTRN	2	Consumption of food nutrition units ***
EMA	8	Net emissions of abatable pollutants ***
EMTOT	8	Net total emissions ***
XFISH	1	Fish catch T (M)
NFISH	1	Non-human consumption of fish T (M)
MFISH	1	Fish imports T (M)
EFISH	1	Fish exports T (M)
AGS	4	Selected agricultural activities T (M)
GMSUB	1	Grain substituted for meat T (M)
RSS	9	Selected resource activities T (M)
MRSLK	9	Resource import slacks (= imports) $ (B)
AGR	1	Residual agriculture $ (B)
RSR	1	Residual resource activities $ (B)
AGM	1	Agricultural margins (food) $ (B)
RSM	2	Resource margins (refining) $ (B)
XT	19	Output of traded commodities $ (B)
XNT	6	Output of non-traded commodities $ (B)
ABATE	5	Level of abatement activities T (M)
ABSLK	5	Abatement equipment slacks T (M)
IEQP	1	Equipment investment $ (B)
IPLT	1	Plant investment $ (B)
INVCH	1	Inventory change investment $ (B)
IIRR	1	Irrigation investment H (M)
ILAND	1	Land development H (M)
SEQP	1	Equipment capital stock $ (B)
SPLT	1	Plant capital stock $ (B)
SINVY	1	Inventory stocks $ (B)
SFAS	1	Stock of foreign assets $ (B)
SLAND	1	Cultivated land area H (M)
HRSS	9	Historical selected resource output ***
ECUMR	9	Cumulative resource output at end of period ***
SCUMR	9	Cumulative resource output at start of period ***
HEQP	1	Historical equipment capital stock $ (B)
HPLT	1	Historical plant capital stock $ (B)
HINVY	1	Historical inventory stock $ (B)
HFAS	1	Historical stock of foreign assets $ (B)
HRFAS	1	Historical net inward capflow $ (B)
INICF	1	1970 net foreign investment income $ (B)
MAGS	4	Imports of selected agriculture T (M)
MAGR	1	Imports of residual agriculture $ (B)
MRSS	9	Imports of selected resources ***
MRSR	1	Imports of residual resources $ (B)
MAGM	1	Imports of agricultural margins $ (B)
MRSM	2	Imports of resource margins $ (B)
MXT	19	Imports of traded goods $ (B)
MSER	1	Imports of services $ (B)
MTR	1	Imports of transport $ (B)
MAID	1	Aid outflow $ (B)
MSLK	1	Import slack $ (B)
EAGS	4	Exports of selected agriculture T (M)
EAGR	1	Exports of residual agriculture $ (B)
ERSS	9	Exports of selected resources ***
ERSR	1	Exports of residual resources $ (B)
EAGM	1	Exports of agricultural margins $ (B)
ERSM	2	Exports of resource margins $ (B)
EXT	19	Exports of traded goods $ (B)
ESER	1	Exports of services $ (B)
ETR	1	Exports of transport $ (B)
EAID	1	Aid inflow $ (B)
ESLK	1	Export slack $ (B)
ECAP	1	Capital inflow $ (B)
MCAP	1	Capital outflow $ (B)
CONST	1	Constant vector ***
DUMA	2	Dummy vectors ***
PAGS	4	Export pool of selected agriculture T (M)
PAGR	1	Export pool of residual agriculture $ (B)
PRSS	9	Export pool of selected resources ***
PRSR	1	Export pool of residual resources $ (B)
PAGM	1	Export pool of agricultural margins $ (B)
PRSM	2	Export pool of resource margins $ (B)
PXT	19	Export pool of traded goods $ (B)
PSER	1	Export pool of services $ (B)
PTR	1	Export pool of transport $ (B)
PAID	1	Export pool of aid inflow $ (B)
PCAP	1	Pool of capital inflow $ (B)
DUMMY	2	Dummy vectors ***

[a] The number following each symbol indicates the number of variables of this type contained in each regional set of equations.

[b] See *Key to units of measurement used for classes of variables* (overleaf) for explanation of the units used for each of the variables.

APPENDIX G

SECTORAL CLASSIFICATION SCHEME AND LIST OF VARIABLES FOR PLATE 2

THE SECTORAL CLASSIFICATION SCHEME AND A DETAILED LIST OF VARIABLES

AB	Abatement	EE	Exports
CA	Calibration	EM	Emissions
CU	Cumulative resource use	FS	Fishing
DU	Dummy and constant variables	IN	Investment and capital
MA	Macro-economic variables	SE	Physicals: agriculture, resources
MM	Imports	WW	World pools
MS	Imports slacks for resources	XS	Output slacks
		XX	Outputs

A. *Column variables*

Type of variable and variable symbol				*Full name of variable*	*Unit of measurement*
Level of abatement activities					
AB	1	ABATE	23.1	Air pollution control	T(M)
AB	2	ABATE	23.2	Primary water treatment	T(M)
AB	3	ABATE	23.3	Secondary water treatment	T(M)
AB	4	ABATE	23.4	Tertiary water treatment	T(M)
AB	5	ABATE	23.5	Solid waste disposal	T(M)
Abatement equations slacks					
AB	6	ABSLK	93.1	Air pollution control	T(M)
AB	7	ABSLK	93.2	Primary water treatment	T(M)
AB	8	ABSLK	93.3	Secondary water treatment	T(M)
AB	9	ABSLK	93.4	Tertiary water treatment	T(M)
AB	10	ABSLK	93.5	Solid waste disposal	T(M)
Calibration slack for resources (shortage)					
CA	1	RSSLK	86.1	Copper	T(M)
CA	2	RSSLK	86.2	Bauxite	T(M)
CA	3	RSSLK	86.3	Nickel	T(000s)
CA	4	RSSLK	86.4	Zinc	T(M)
CA	5	RSSLK	86.5	Lead	T(M)
CA	6	RSSLK	86.6	Iron	T(M)
CA	7	RSSLK	86.7	Petroleum	T(M)
CA	8	RSSLK	86.8	Natural gas	T(M coal equivalent)
CA	9	RSSLK	86.9	Coal	T(M coal equivalent)
					T(M coal equivalent)
Historical selected resource output					
CU	1	HRSS	90.1	Copper	T(M)
CU	2	HRSS	90.2	Bauxite	T(M)
CU	3	HRSS	90.3	Nickel	T(000s)
CU	4	HRSS	90.4	Zinc	T(M)
CU	5	HRSS	90.5	Lead	T(M)
CU	6	HRSS	90.6	Iron	T(M)
CU	7	HRSS	90.7	Petroleum	T(M coal equivalent)
CU	8	HRSS	90.8	Natural gas	T(M coal equivalent)
CU	9	HRSS	90.9	Coal	T(M coal equivalent)
Cumulative resource output at end of period					
CU	10	ECUMR	74.1	Copper	T(M)
CU	11	ECUMR	74.2	Bauxite	T(M)
CU	12	ECUMR	74.3	Nickel	T(000s)
CU	13	ECUMR	74.4	Zinc	T(M)
CU	14	ECUMR	74.5	Lead	T(M)
CU	15	ECUMR	74.6	Iron	T(M)
CU	16	ECUMR	74.7	Petroleum	T(M coal equivalent)
CU	17	ECUMR	74.8	Natural gas	T(M coal equivalent)
CU	18	ECUMR	74.9	Coal	T(M coal equivalent)
Cumulative resource output at start of period					
CU	19	SCUMR	75.1	Copper	T(M)
CU	20	SCUMR	75.2	Bauxite	T(M)
CU	21	SCUMR	75.3	Nickel	T(000s)
CU	22	SCUMR	75.4	Zinc	T(M)
CU	23	SCUMR	75.5	Lead	T(M)
CU	24	SCUMR	75.6	Iron	T(M)
CU	25	SCUMR	75.7	Petroleum	T(M coal equivalent)
CU	26	SCUMR	75.8	Natural gas	T(M coal equivalent)
CU	27	SCUMR	75.9	Coal	T(M coal equivalent)

A. *Column variables* (continued)

Type of variable and variable symbol				Full name of variable	Unit of measurement
Dummy and constant variables					
DU	1	GMSUR	82.1	Grain substituted for meat	T(M)
DU	2	CONST	61.1	Constant vector	
Dummy variables					
DU	3	DUMA	62.1	Dummy	
DU	4	DUMA	62.2	Dummy	
DU	5	DUMMY	73.1	Dummy	
DU	6	DUMMY	73.2	Dummy	
Exports of selected agriculture					
EE	1	EAGS	50.1	Livestock	T(M)
EE	2	EAGS	50.2	Oil-crops	T(M)
EE	3	EAGS	50.3	Grains	T(M)
EE	4	EAGS	50.4	Roots	T(M)
EE	5	EAGR	51.1	Exports of residual agriculture	$(B)
Exports of selected resources					
EE	6	ERSS	52.1	Copper	T(M)
EE	7	ERSS	52.2	Bauxite	T(M)
EE	8	ERSS	52.3	Nickel	T(000s)
EE	9	ERSS	52.4	Zinc	T(M)
EE	10	ERSS	52.5	Lead	T(M)
EE	11	ERSS	52.6	Iron	T(M)
EE	12	ERSS	52.7	Petroleum	T(M coal equivalent)
EE	13	ERSS	52.8	Natural gas	T(M coal equivalent)
EE	14	ERSS	52.9	Coal	T(M coal equivalent)
EE	15	ERSR	53.1	Exports of residual resources	$(B)
EE	16	EAGM	54.1	Exports of agricultural margins	$(B)
Exports of resource margins					
EE	17	ERSM	55.1	Petroleum refining	$(B)
EE	18	ERSM	55.2	Primary metal processing	$(B)
Exports of traded goods					
EE	19	EXT	56.1	Textiles, apparel	$(B)
EE	20	EXT	56.2	Wood and cork	$(B)
EE	21	EXT	56.3	Furniture, fixtures	$(B)
EE	22	EXT	56.4	Paper	$(B)
EE	23	EXT	56.5	Printing	$(B)
EE	24	EXT	56.6	Rubber	$(B)
EE	25	EXT	56.7	Industrial chemicals	$(B)
EE	26	EXT	56.8	Fertilizer	T(M)
EE	27	EXT	56.9	Miscellaneous chemical products	$(B)
EE	28	EXT	56.10	Cement	$(B)
EE	29	EXT	56.11	Glass	$(B)
EE	30	EXT	56.12	Motor vehicles	$(B)
EE	31	EXT	56.13	Shipbuilding	$(B)
EE	32	EXT	56.14	Aircraft	$(B)
EE	33	EXT	56.15	Metal products	$(B)
EE	34	EXT	56.16	Machinery	$(B)
EE	35	EXT	56.17	Electric machinery	$(B)
EE	36	EXT	56.18	Professional instruments	$(B)
EE	37	EXT	56.19	Watches, clocks	$(B)
EE	38	ESER	57.1	Exports of services	$(B)
EE	39	ETR	80.1	Exports of transport	$(B)
EE	40	EAID	59.1	Aid (inflow)	$(B)
EE	41	ESLK	60.1	Export slack	$(B)
EE	42	ECAP	58.1	Foreign capital (inflow)	$(B)
Net emissions of abatable pollutants					
EM	1	EMA	12.1	Pesticides	T(M)
EM	2	EMA	12.2	Particulates	T(M)
EM	3	EMA	12.3	Biological oxygen demand	T(M)
EM	4	EMA	12.4	Nitrogen water pollution	T(M)
EM	5	EMA	12.5	Phosphates	T(M)
EM	6	EMA	12.6	Suspended solids	T(M)
EM	7	EMA	12.7	Dissolved solids	T(M)
EM	8	EMA	12.8	Solid waste	T(M)
Net total emissions					
EM	9	EMTOT	13.1	Pesticides	T(M)
EM	10	EMTOT	13.2	Particulates	T(M)
EM	11	EMTOT	13.3	Biological oxygen demand	T(M)

A. *Column variables* (continued)

Type of variable and variable symbol				*Full name of variable*	*Unit of measurement*
EM	12	EMTOT	13.4	Nitrogen water pollution	T(M)
EM	13	EMTOT	13.5	Phosphates	T(M)
EM	14	EMTOT	13.6	Suspended solids	T(M)
EM	15	EMTOT	13.7	Dissolved solids	T(M)
EM	16	EMTOT	13.8	Solid waste	T(M)
Fishing variables					
FS	1	XFISH	76.1	Fish catch	T(M)
FS	2	NFISH	94.1	Non-human consumption of fish	T(M)
FS	3	MFISH	77.1	Fish imports	T(M)
FS	4	EFISH	78.1	Fish exports	T(M)
Investment and capital variables					
IN	1	IEQP	26.1	Equipment investment	S(B)
IN	2	IPLT	25.1	Plant investment	S(B)
IN	3	INVCH	96.1	Inventory change investment	S(B)
IN	4	IIRR	27.1	Irrigation investment	H(M)
IN	5	ILAND	28.1	Land development	H(M)
IN	6	SEQP	30.1	Equipment capital stock	S(B)
IN	7	SPLT	29.1	Plant capital stock	S(B)
IN	8	SINVY	95.1	Inventory stocks	S(B)
IN	9	SFAS	31.1	Stock of foreign assets	S(B)
IN	10	SLAND	33.1	Cultivated land area	H(M)
IN	11	HEQP	35.1	Historical equipment capital stock	S(B)
IN	12	HPLT	34.1	Historical plant capital stock	S(B)
IN	13	HINVY	97.1	Historical inventory stock	S(B)
IN	14	HFAS	36.1	Historical stock of foreign assets	S(B)
IN	15	HRFAS	91.1	Historical net inward capital flow	S(B)
IN	16	INICF	92.1	1970 net foreign investment income	S(B)
Macro-economic variables					
MA	1	GDP	1.1	Gross domestic product	S(B)
MA	2	CONS	2.1	Consumption level	S(B)
MA	3	DSAVE	8.1	Excess savings potential	S(B)
MA	4	INV	3.1	Investment level	S(B)
MA	5	GOV	4.1	Government expenditures	S(B)
MA	6	BAL	5.1	Balance of payments	S(B)
MA	7	IMPRT	6.1	Total imports	S(B)
MA	8	EXPRT	7.1	Total exports	S(B)
MA	9	POP	8.1	Population	(M)
MA	10	URBAN	9.1	Urban population	(M)
MA	11	LABOR	10.1	Employment	MY(M)
Consumption of food nutrition units					
MA	12	NUTRN	11.1	Calories	(KCAL/DAY)(B)
MA	13	NUTRN	11.2	Proteins	(GRAMS/DAY)
Imports of selected agriculture					
MM	1	MAGS	39.1	Livestock	T(M)
MM	2	MAGS	39.2	Oil-crops	T(M)
MM	3	MAGS	39.3	Grains	T(M)
MM	4	MAGS	39.4	Roots	T(M)
MM	5	MAGR	40.1	Imports of residual agriculture	S(B)
Imports of selected resources					
MM	6	MRSS	41.1	Copper	T(M)
MM	7	MRSS	41.2	Bauxite	T(M)
MM	8	MRSS	41.3	Nickel	T(000s)
MM	9	MRSS	41.4	Zinc	T(M)
MM	10	MRSS	41.5	Lead	T(M)
MM	11	MRSS	41.6	Iron	T(M)
MM	12	MRSS	41.7	Petroleum	T(M coal equivalent)
MM	13	MRSS	41.8	Natural gas	T(M coal equivalent)
Imports of selected resources					
MM	14	MRSS	41.9	Coal	T(M coal equivalent)
MM	15	MRSR	42.1	Imports of residual resources	S(B)
MM	16	MAGM	43.1	Imports of agricultural margins	S(B)
Imports of resource margins					
MM	17	MRSM	44.1	Petroleum refining	S(B)
MM	18	MRSM	44.2	Primary metal processing	S(B)
Imports of traded goods					
MM	19	MXT	45.1	Textiles, apparel	S(B)
MM	20	MXT	45.2	Wood and cork	S(B)

A. *Column variables* (continued)

Type of variable and variable symbol		*Full name of variable*	*Unit of measurement*
MM 21 MXT	45.3	Furniture, fixtures	S(B)
MM 22 MXT	45.4	Paper	S(B)
MM 23 MXT	45.5	Printing	S(B)
MM 24 MXT	45.6	Rubber	S(B)
MM 25 MXT	45.7	Industrial chemicals	S(B)
MM 26 MXT	45.8	Fertilizer	T(M)
MM 27 MXT	45.9	Miscellaneous chemical products	S(B)
MM 28 MXT	45.10	Cement	S(B)
MM 29 MXT	45.11	Glass	S(B)
MM 30 MXT	45.12	Motor vehicles	S(B)
MM 31 MXT	45.13	Shipbuilding	S(B)
MM 32 MXT	45.14	Aircraft	S(B)
MM 33 MXT	45.15	Metal products	S(B)
MM 34 MXT	45.16	Machinery	S(B)
MM 35 MXT	45.17	Electric machinery	S(B)
MM 36 MXT	45.18	Professional instruments	S(B)
MM 37 MXT	45.19	Watches, clocks	S(B)
MM 38 MSER	46.1	Imports of service	S(B)
MM 39 MTR	79.1	Imports of transport	S(B)
MM 40 MAID	48.1	Aid (inflow)	S(B)
MM 41 MSLK	49.1	Import slack	S(B)
MM 42 MCAP	47.1	Foreign capital (outflow)	S(B)
Resource import slacks			
MS 1 MRSLK	99.1	Copper	T(M)
MS 2 MRSLK	99.2	Bauxite	T(M)
MS 3 MRSLK	99.3	Nickel	T(000s)
MS 4 MRSLK	99.4	Zinc	T(M)
MS 5 MRSLK	99.5	Lead	T(M)
MS 6 MRSLK	99.6	Iron	T(M)
MS 7 MRSLK	99.7	Petroleum	T(M coal equivalent)
MS 8 MRSLK	99.8	Natural gas	T(M coal equivalent)
MS 9 MRSLK	99.9	Coal	T(M coal equivalent)
Selected agricultural activities			
SE 1 AGS	14.1	Livestock	T(M)
SE 2 AGS	14.2	Oil-crops	T(M)
SE 3 AGS	14.3	Grains	T(M)
SE 4 AGS	14.4	Roots	T(M)
Selected resource activities			
SE 5 RSS	16.1	Copper	T(M)
SE 6 RSS	16.2	Bauxite	T(M)
SE 7 RSS	16.3	Nickel	T(000s)
SE 8 RSS	16.4	Zinc	T(M)
SE 9 RSS	16.5	Lead	T(M)
SE 10 RSS	16.6	Iron	T(M)
SE 11 RSS	16.7	Petroleum	T(M coal equivalent)
SE 12 RSS	16.8	Natural gas	T(M coal equivalent)
SE 13 RSS	16.9	Coal	T(M coal equivalent)
Export pool of selected agriculture			
WW 1 PAGS	63.1	Livestock	T(M)
WW 2 PAGS	63.2	Oil-crops	T(M)
WW 3 PAGS	63.3	Grains	T(M)
WW 4 PAGS	63.4	Roots	T(M)
WW 5 PAGR	64.1	Export pool of residual agriculture	S(B)
Export pool of selected resources			
WW 6 PRSS	65.1	Copper	T(M)
WW 7 PRSS	65.2	Bauxite	T(M)
WW 8 PRSS	65.3	Nickel	T(000s)
WW 9 PRSS	65.4	Zinc	T(M)
WW 10 PRSS	65.5	Lead	T(M)
WW 11 PRSS	65.6	Iron	T(M)
WW 12 PRSS	65.7	Petroleum	T(M coal equivalent)
WW 13 PRSS	65.8	Natural gas	T(M coal equivalent)
WW 14 PRSS	65.9	Coal	T(M coal equivalent)
WW 15 PRSR	66.1	Export pool of residual resources	S(B)
WW 16 PAGM	67.1	Export pools of agricultural margins	S(B)
Export pool of resource margins			
WW 17 PRSM	68.1	Petroleum refining	S(B)
WW 18 PRSM	68.2	Primary metal processing	S(B)

A. *Column variables* (continued)

Type of variable and variable symbol		*Full name of variable*	*Unit of measurement*
Export pool of traded goods			
WW 19 PXT	69.1	Textiles, apparel	$(B)
WW 20 PXT	69.2	Wood and cork	$(B)
WW 21 PXT	69.3	Furniture, fixtures	$(B)
WW 22 PXT	69.4	Paper	$(B)
WW 23 PXT	69.5	Printing	$(B)
WW 24 PXT	69.6	Rubber	$(B)
WW 25 PXT	69.7	Industrial chemicals	$(B)
WW 26 PXT	69.8	Fertilizer	T(M)
WW 27 PXT	69.9	Miscellaneous chemical products	$(B)
WW 28 PXT	69.10	Cement	$(B)
WW 29 PXT	69.11	Glass	$(B)
WW 30 PXT	69.12	Motor vehicles	$(B)
WW 31 PXT	69.13	Shipbuilding	$(B)
WW 32 PXT	69.14	Aircraft	$(B)
WW 33 PXT	69.15	Metal products	$(B)
WW 34 PXT	69.16	Machinery	$(B)
WW 35 PXT	69.17	Electric machinery	$(B)
WW 36 PXT	69.18	Professional instruments	$(B)
WW 37 PXT	69.19	Watches, clocks	$(B)
WW 38 PSER	70.1	Export pool of services	$(B)
WW 39 PTR	81.1	Export pool of transport	$(B)
WW 40 PAID	72.1	Pool of aid (inflow)	$(B)
WW 41 PCAP	71.1	Pool of foreign capital (inflow)	$(B)
Output slacks			
XS 1 XSLK	98.1	Primary metal	$(B)
XS 2 XSLK	98.2	Rubber	$(B)
XS 3 XSLK	98.3	Fertilizer	T(M)
XS 4 XSLK	98.4	Cement	$(B)
XS 5 XSLK	98.5	Motor vehicles	$(B)
XS 6 XSLK	98.6	Aircraft	$(B)
XS 7 XSLK	98.7	Machinery	$(B)
XS 8 XSLK	98.8	Electric machinery	$(B)
Output variables			
XX 1 AGR	17.1	Residual agriculture	$(B)
XX 2 RSR	18.1	Residual resource activities	$(B)
XX 3 AGM	19.1	Agricultural margins (food)	$(B)
Resource margins (refining)			
XX 4 RSM	20.1	Petroleum refining	$(B)
XX 5 RSM	20.2	Primary metal processing	$(B)
Output of traded commodities			
XX 6 XT	21.1	Textiles, apparel	$(B)
XX 7 XT	21.2	Wood and cork	$(B)
XX 8 XT	21.3	Furniture, fixtures	$(B)
XX 9 XT	21.4	Paper	$(B)
XX 10 XT	21.5	Printing	$(B)
XX 11 XT	21.6	Rubber	$(B)
XX 12 XT	21.7	Industrial chemicals	$(B)
XX 13 XT	21.8	Fertilizer	T(M)
XX 14 XT	21.9	Miscellaneous chemical products	$(B)
XX 15 XT	21.10	Cement	$(B)
XX 16 XT	21.11	Glass	$(B)
XX 17 XT	21.12	Motor vehicles	$(B)
XX 18 XT	21.13	Shipbuilding	$(B)
XX 19 XT	21.14	Aircraft	$(B)
XX 20 XT	21.15	Metal products	$(B)
XX 21 XT	21.16	Machinery	$(B)
XX 22 XT	21.17	Electric machinery	$(B)
XX 23 XT	21.18	Professional instruments	$(B)
XX 24 XT	21.19	Watches, clocks	$(B)
Output of non-traded commodities			
XX 25 XNT	22.1	Electricity, water	$(B)
XX 26 XNT	22.2	Construction	$(B)
XX 27 XNT	22.3	Trade	$(B)
XX 28 XNT	22.4	Transport	$(B)
XX 29 XNT	22.5	Communication	$(B)
XX 30 XNT	22.6	Services	$(B)

B. *Row variables*

Type of variable and variable symbol				Full name of variable	Unit of measurement
Cumulative resource output at end of period					
CU	1	ECUMR	50.1	Copper	T(M)
CU	2	ECUMR	50.2	Bauxite	T(M)
CU	3	ECUMR	50.3	Nickel	T(000s)
CU	4	ECUMR	50.4	Zinc	T(M)
CU	5	ECUMR	50.5	Lead	T(M)
CU	6	ECUMR	50.6	Iron	T(M)
CU	7	ECUMR	50.7	Petroleum	T(M coal equivalent)
CU	8	ECUMR	50.8	Natural gas	T(M coal equivalent)
CU	9	ECUMR	50.9	Coal	T(M coal equivalent)
Dummy variables					
DU	1	DUMMY	49.1	Dummy	
DU	2	DUMMY	49.2	Dummy	
Exports of selected agriculture					
EE	1	EAGS	39.1	Meat and fish	T(M)
EE	2	EAGS	39.2	Oil-crops	T(M)
EE	3	EAGS	39.3	Grains	T(M)
EE	4	EAGS	39.4	Roots	T(M)
EE	5	EAGR	40.1	Exports of residual agriculture	S(B)
Exports of selected resources					
EE	6	ERSS	41.1	Copper	T(M)
EE	7	ERSS	41.2	Bauxite	T(M)
EE	8	ERSS	41.3	Nickel	T(000s)
EE	9	ERSS	41.4	Zinc	T(M)
EE	10	ERSS	41.5	Lead	T(M)
EE	11	ERSS	41.6	Iron	T(M)
EE	12	ERSS	41.7	Petroleum	T(M coal equivalent)
EE	13	ERSS	41.8	Natural gas	T(M coal equivalent)
EE	14	ERSS	41.9	Coal	T(M coal equivalent)
EE	15	ERSR	42.1	Exports of residual resources	S(B)
EE	16	EAGM	43.1	Exports of agricultural margins	S(B)
Exports of resource margins					
EE	17	ERSM	44.1	Petroleum refining	S(B)
EE	18	ERSM	44.2	Primary metal processing	S(B)
Exports of traded goods					
EE	19	EXT	45.1	Textiles, apparel	S(B)
EE	20	EXT	45.2	Wood and cork	S(B)
EE	21	EXT	45.3	Furniture, fixtures	S(B)
EE	22	EXT	45.4	Paper	S(B)
EE	23	EXT	45.5	Printing	S(B)
EE	24	EXT	45.6	Rubber	S(B)
EE	25	EXT	45.7	Industrial chemicals	S(B)
EE	26	EXT	45.8	Fertilizer	T(M)
EE	27	EXT	45.9	Miscellaneous chemical products	S(B)
EE	28	EXT	45.10	Cement	S(B)
EE	29	EXT	45.11	Glass	S(B)
EE	30	EXT	45.12	Motor vehicles	S(B)
EE	31	EXT	45.13	Shipbuilding	S(B)
EE	32	EXT	45.14	Aircraft	S(B)
EE	33	EXT	45.15	Metal products	S(B)
EE	34	EXT	45.16	Machinery	S(B)
EE	35	EXT	45.17	Electric machinery	S(B)
EE	36	EXT	45.18	Professional instruments	S(B)
EE	37	EXT	45.19	Watches, clocks	S(B)
EE	38	ESER	46.1	Exports of services	S(B)
EE	39	ETR	52.1	Exports of transport	S(B)
EE	40	EAID	48.1	Aid (inflow)	S(B)
EE	41	ECAP	47.1	Foreign capital (inflow)	S(B)
Emissions of abatable pollutants					
EM	1	EMA	10.1	Pesticides	T(M)
EM	2	EMA	10.2	Particulates	T(M)
EM	3	EMA	10.3	Biological oxygen demand	T(M)
EM	4	EMA	10.4	Nitrogen water pollution	T(M)
EM	5	EMA	10.5	Phosphates	T(M)
EM	6	EMA	10.6	Suspended solids	T(M)
EM	7	EMA	10.7	Dissolved solids	T(M)
EM	8	EMA	10.8	Solid waste	T(M)

B. *Row variables* (continued)

Type of variable and variable symbol				*Full name of variable*	*Unit of measurement*
Emissions of non-abatable pollutants					
EM	9	EMNA	11.1	Pesticides	T(M)
EM	10	EMNA	11.2	Particulates	T(M)
EM	11	EMNA	11.3	Biological oxygen demand	T(M)
EM	12	EMNA	11.4	Nitrogen water pollution	T(M)
EM	13	EMNA	11.5	Phosphates	T(M)
EM	14	EMNA	11.6	Suspended solids	T(M)
EM	15	EMNA	11.7	Dissolved solids	T(M)
EM	16	EMNA	11.8	Solid waste	T(M)
Abatement determination					
EM	17	ABDET	53.1	Air pollution control	T(M)
EM	18	ABDET	53.2	Primary water treatment	T(M)
EM	19	ABDET	53.3	Secondary water treatment	T(M)
EM	20	ABDET	53.4	Tertiary water treatment	T(M)
EM	21	ABDET	53.5	Solid waste disposal	T(M)
Investment and capital variables					
IN	1	IEQP	21.1	Equipment investment	$(B)
IN	2	IPLT	20.1	Plant investment	$(B)
IN	3	INVCH	55.1	Inventory change investment equation	$(B)
IN	4	SEQP	25.1	Equipment capital stock	$(B)
IN	5	SPLT	24.1	Plant capital stock	$(B)
IN	6	SINVY	54.1	Inventory stock equation	$(B)
IN	7	SFAS	26.1	Stock of foreign assets	$(B)
IN	8	SLAND	28.1	Cultivated land area	H(M)
Macro-economic variables					
MA	1	GDP	1.1	Gross domestic product	$(B)
MA	2	SAVE	2.1	Savings equation	$(B)
MA	3	INV	3.1	Investment equation	$(B)
MA	4	GOV	4.1	Government expenditures	$(B)
MA	5	BAL	5.1	Balance of payments	$(B)
MA	6	IMPRT	6.1	Total imports	$(B)
MA	7	EXPRT	7.1	Total exports	$(B)
MA	8	LABOR	8.1	Employment	MY(B)
Consumption of food nutrition					
MA	9	NUTRN	9.1	Calories	(KCAL/DAY)(B)
MA	10	NUTRN	9.2	Proteins	(GRAMS/DAY)
Imports of selected agriculture					
MM	1	MAGS	29.1	Meat and fish	T(M)
MM	2	MAGS	29.2	Oil-crops	T(M)
MM	3	MAGS	29.3	Grains	T(M)
MM	4	MAGS	29.4	Roots	T(M)
MM	5	MAGR	30.1	Imports of residual agriculture	$(B)
Imports of selected resources					
MM	6	MRSS	31.1	Copper	T(M)
MM	7	MRSS	31.2	Bauxite	T(M)
MM	8	MRSS	31.3	Nickel	T(000s)
MM	9	MRSS	31.4	Zinc	T(M)
MM	10	MRSS	31.5	Lead	T(M)
MM	11	MRSS	31.6	Iron	T(M)
MM	12	MRSS	31.7	Petroleum	T(M coal equivalent)
MM	13	MRSS	31.8	Natural gas	T(M coal equivalent)
MM	14	MRSS	31.9	Coal	T(M coal equivalent)
MM	15	MRSR	32.1	Imports of residual resources	$(B)
MM	16	MAGM	33.1	Imports of agricultural margins	$(B)
Imports of resource margins					
MM	17	MRSM	34.1	Petroleum refining	$(B)
MM	18	MRSM	34.2	Primary metal processing	$(B)
Imports of traded goods					
MM	19	MXT	35.1	Textiles, apparel	$(B)
MM	20	MXT	35.2	Wood and cork	$(B)
MM	21	MXT	35.3	Furniture, fixtures	$(B)
MM	22	MXT	35.4	Paper	$(B)
MM	23	MXT	35.5	Printing	$(B)
MM	24	MXT	35.6	Rubber	$(B)
MM	25	MXT	35.7	Industrial chemicals	$(B)
MM	26	MXT	35.8	Fertilizer	T(M)
MM	27	MXT	35.9	Miscellaneous chemical products	$(B)

B. *Row variables* (continued)

Type of variable and variable symbol		*Full name of variable*	*Unit of measurement*
Imports of traded goods			
MM 28 MXT	35.10	Cement	$(B)
MM 29 MXT	35.11	Glass	$(B)
MM 30 MXT	35.12	Motor vehicles	$(B)
MM 31 MXT	35.13	Shipbuilding	$(B)
MM 32 MXT	35.14	Aircraft	$(B)
MM 33 MXT	35.15	Metal products	$(B)
MM 34 MXT	35.16	Machinery	$(B)
MM 35 MXT	35.17	Electric machinery	$(B)
MM 36 MXT	35.18	Professional instruments	$(B)
MM 37 MXT	35.19	Watches, clocks	$(B)
MM 38 MSER	36.1	Imports of services	$(B)
MM 39 MTR	51.1	Imports of transport	$(B)
MM 40 MAID	38.1	Aid (outflow)	$(B)
MM 41 MCAP	37.1	Foreign capital (outflow)	$(B)
Selected agricultural commodity			
SE 1 AGS	12.1	Meat and fish	T(M)
SE 2 AGS	12.2	Oil-crops	T(M)
SE 3 AGS	12.3	Grains	T(M)
SE 4 AGS	12.4	Roots	T(M)
Selected resources commodity balance			
SE 5 RSS	13.1	Copper	T(M)
SE 6 RSS	13.2	Bauxite	T(M)
SE 7 RSS	13.3	Nickel	T(000s)
SE 8 RSS	13.4	Zinc	T(M)
SE 9 RSS	13.5	Lead	T(M)
SE 10 RSS	13.6	Iron	T(M)
SE 11 RSS	13.7	Petroleum	T(M coal equivalent)
SE 12 RSS	13.8	Natural gas	T(M coal equivalent)
SE 13 RSS	13.9	Coal	T(M coal equivalent)
Output variables			
XX 1 AGR	14.1	Residual agriculture	$(B)
XX 2 RSR	15.1	Residual resource commodity balance	$(B)
XX 3 AGM	16.1	Agricultural margins (food)	$(B)
Resource margins (refining)			
XX 4 RSM	17.1	Petroleum refining	$(B)
XX 5 RSM	17.2	Primary metal processing	$(B)
Output of traded commodities			
XX 6 XT	18.1	Textiles, apparel	$(B)
XX 7 XT	18.2	Wood and cork	$(B)
XX 8 XT	18.3	Furniture, fixtures	$(B)
XX 9 XT	18.4	Paper	$(B)
XX 10 XT	18.5	Printing	$(B)
XX 11 XT	18.6	Rubber	$(B)
XX 12 XT	18.7	Industrial chemicals	$(B)
XX 13 XT	18.8	Fertilizer	T(M)
XX 14 XT	18.9	Miscellaneous chemical products	$(B)
XX 15 XT	18.10	Cement	$(B)
XX 16 XT	18.11	Glass	$(B)
XX 17 XT	18.12	Motor vehicles	$(B)
XX 18 XT	18.13	Shipbuilding	$(B)
XX 19 XT	18.14	Aircraft	$(B)
XX 20 XT	18.15	Metal products	$(B)
XX 21 XT	18.16	Machinery	$(B)
XX 22 XT	18.17	Electric machinery	$(B)
XX 23 XT	18.18	Professional instruments	$(B)
XX 24 XT	18.19	Watches, clocks	$(B)
Output of non-traded commodities			
XX 25 XNT	19.1	Electricity, water	$(B)
XX 26 XNT	19.2	Construction	$(B)
XX 27 XNT	19.3	Trade	$(B)
XX 28 XNT	19.4	Transport	$(B)
XX 29 XNT	19.5	Communication	$(B)
XX 30 XNT	19.6	Services	$(B)

Source: Future of the World Economy (pp. 75-82) by Leontief et al., 1977, New York: Oxford University Press.

APPENDIX H

THE UNITED NATIONS MODEL IN CONVENTIONAL EQUATION FORM

THE MODEL IN CONVENTIONAL EQUATION FORM

*Equations**

1: Gross domestic product
M * GNP = CONS + INV + GOV − IMPRT + EXPRT
+ P * URBAN + P * ABATE + INVCH.

2: Savings
DSAVE = % * GNP − P * INV − P * INVCH − MAID
+ EAID + ECAP − MCAP.

3: Investment
INV = IEQP + IPLT + P * IIRR + P * ILAND.

4: Government expenditures
GOV = % * GNP

5: Total imports
IMPRT = P * MFISH + P * MAGS + MAGR + P * MRSS
+ MRSR + MAGM + MRSM + P * MXT
+ MSER + MTR.

6: Total exports
EXPRT = P * EFISH + P * EAGS + EAGR + P * ERSS
+ ERSR + EAGM + ERSM + P * EXT + ESER
+ ETR.

7: Balance of payments
BAL = P * MFISH + P * EFISH + M * SFAS + INICF
− P * MAGS − P * MAGR − P * MRSS − P
* MRSR − P * MAGM − P * MXT − P * MSER
− P * MTR − MAID + P * EAGS + P * EAGR
+ P * ERSS + P * ERSR + P * EAGM + P * ERSM
+ P * EXT + P + ESER + P * ETR + EAID
+ ECAP − MCAP.

8: Employment
LABOR = L * CONS + L * GOV + L * POP + L * URABN
+ L * XFISH + L * AGS + L * RSS + L * AGR
+ L * RSR + L * AGM + L * RSM + L * XT
+ L * XNT + L * ABATE + L * IIRR
+ L * ILAND.

9-10: Consumption of food nutrient units
NUTRN = M * CONS + M * POP.

11-15: Abatement determination
ABSLK = − M * ABATE.

16-23: Emissions of abatable pollutants
EMA = E * CONS + E * POP + E * URBAN
+ E * AGS + E * RSS + E * AGR + E * RSR
+ E * AGM + E * RSM + E * XT + E * XNT
− M * ABATE.

24-31: Emissions of non-abatable pollutants
EMTOT = EMA + E * ABATE.

32-35: Selected agricultural commodity balance
AGS = − C * CONS − C * GOV − C * POP − U
* URBAN + M * XFISH − M * NFISH + M
* MFISH − M * EFISH + (1 + @) * AGS + M
* GMSUB + @ * RSS + @ * AGR + @ * RSR
+ @ * AGM + @ * RSM + @ * XT + @ * XNT
+ @ * ABATE − S * IEQP − S * IPLT − S
* INVCH − S * IIRR − S * ILAND + MAGS
− EAGS.

36: Residual agriculture
AGR = − C * CONS − C * GOV − C * POP
− U * URBAN + @ * XFISH + @ * AGS
+ @ * RSS + (1 + @) * AGR + @ * RSR
+ @ * AGM + @ * RSM + @ * XT + @ * XNT
+ @ * ABATE − S * IEQP − S * IPLT − S
* INVCH − S * IIRR − S * ILAND + MAGR
− EAGR.

37-45: Selected resource commodity balance
RSS = − C * CONS − C * GOV − C * POP
− U * URBAN + @ * XFISH + @ * AGS
+ (1 + @) * RSS + @ * AGR + @ * RSR + @
* AGM + @ * RSM + @ * XT + @ * XNT
+ @ * ABATE − S * IEQP − S * IPLT − S
* INVCH − S * IIRR − S * ILAND + MRSS
− ERSS.

46: Residual resource commodity balance
RSR = − C * CONS − C * GOV − C * POP − U * URBAN
+ @ * XFISH + @ * AGS + @ * RSS + @ * AGR
+ (1 + @) * RSR + @ * AGM + @ * RSM + @
* XT + @ * XNT + @ * ABATE − S * IEQP − S
* IPLT − S * INVCH − S * IIRR − S * ILAND
+ MRSR − ERSR.

47: Agricultural margins (food)
AGM = − C * CONS − C * GOV − C * POP − U
* URBAN + @ * XFISH + @ * AGS + @ * RSS
+ @ * AGR + @ * RSR + (1 + @) * AGM
+ @ * RSM + @ * XT + @ * XNT + @
* ABATE − S * IEQP − S * IPLT − S * INVCH
− S * IIRR − S * ILAND + MAGM − EAGM.

48-49: Resource margins (refining)
RSM = − C * CONS − C * GOV − C * POP − U
* URBAN + @ * XFISH + @ * AGS + @
* RSS + @ * AGR + @ * RSR + @ * AGM
+ (1 + @) * RSM + @ * XT + @ * XNT + @
* ABATE − S * IEQP − S * EPLT − S * INVCH
− S * IIRR − S * ILAND + MRSM − ERSM.

50-68: Output of traded commodities
XT = − C * CONS − C * GOV − C * POP − U
* URBAN + @ * XFISH + @ * AGS + @ * RSS
+ @ * AGR + @ * RSR + @ * AGM + @
* RSM + (1 + @) * XT + @ * XNT + @
* ABATE − S * IEQP − S * IPLT − S * INVCH
− S * IIRR − S * ILAND + MXT − EXT.

69-74: Output of non-traded commodities
XNT = − C * CONS − C * GOV − C * POP − U
* URBAN + @ * XFISH + @ * AGS + @
* RSS + @ * AGR + @ * RSR + @ * AGM
+ @ * RSM + @ * XT + (1 + @) * XNT + @
* ABATE − S * IEQP − S * IPLT − S * IIRR
− S * ILAND + M * MSER − M * MTR − M
* ESER − M * ETR.

75: Equipment investment
IEQP = G * SEQP + G * HEQP.

* See key to coefficient symbols, p. 84.

76: Plant investment
IPLT = G • SPLT + G • HPLT.

77: Inventory change investment
INVCH = G • SINVY + G • HINVY.

78-86: Cumulative resource output at end of period
ECUMR = G • RSS + G • HRSS + SCUMR.

87: Equipment capital stock
SEQP = K • URBAN + K • XFISH + K • AGS + K • RSS + K • AGR + K • RSR + K • AGM + K • RSM + K • XT + K • XNT + K • ABATE + K • IIRR + K • ILAND.

88: Plant capital stock
SPLT = K • CONS + K • POP + K • URBAN + K • XFISH + K • AGS + K • RSS + K • AGR + K • RSR + K • AGM + K • RSM + K • XT + K • XNT + K • ABATE + K • IIRR + K • ILAND.

89: Inventory stock
SINVY = K • AGS + K • RSS + K • AGR + K • RSR + K • AGM + K • RSM + K • XT.

90: Stock of foreign assets
SFAS = G • BAL – SFAS + HFAS + G • HRFAS – G • ECAP + G • MCAP.

91: Cultivated land area
SLAND = K • AGS + K • AGR.

92-95: Imports of selected agriculture
MAGS = A • AGS • T • MSLK.

96: Imports of residual agriculture
MAGR = A • AGR + T • MSLK.

97-105: Imports of selected resources
MRSS = A • RSS + MRSLK + T • MSLK.

106: Imports of residual resources
MRSR = A • RSR + T • MSLK.

107: Imports of agricultural margins
MAGM = D • MFISH + D • MAGS + D • MAGR + T • MSLK.

108-109: Imports of resource margins
MRSM = D • MRSS + D • MRSR + T • MSLK + M • CONST.

110-128: Imports of traded goods
MXT = A • XT + T • MSLK.

129: Imports of services
MSER = M • GDP + T • MSLK.

130: Imports of transport
MTR = M • GDP + M • IMPRT + M • EXPRT.

131: Foreign aid (outflow)
MAID = M • GDP.

132-135: Exports of selected agriculture
EAGS = T • ESLK + B • PAGS.

136: Exports of residual agriculture
EAGR = T • ESLK + B • PAGR.

137-145: Exports of selected resources
ERSS = T • ESLK + B • PRSS.

146: Exports of residual resources
ERSR = T • ESLK + B • PRSR.

147: Exports of agricultural margins
EAGM = D • EFISH + D • EAGS + D • EAGR – T • ESLK + B • PAGM.

148-149: Exports of resource margins
ERSM = D • ERSS + D • ERSR – T • ESLK + M • CONST + B • PRSM.

150-168: Exports of traded goods
EXT = T • ESLK + B • PXT.

169: Exports of services
ESER = T • ESLK + B • PSER.

170: Exports of transport
ETR = B • PTR.

171: Foreign aid (inflow)
EAID = B • PAID.

172: Foreign capital (inflow)
ECAP = M • GDP.

173: Foreign capital (outflow)
MCAP = B • PCAP.

174-175: Dummy equations
DUMMY = DUMA.

Key to coefficient symbols

A	Import to output ratios	P	Prices
B	World export pool shares	S	Structure of investment demand
C	Consumption coefficients	T	Marginal trade composition
D	Margin trade to physical units	U	Urban amenities input structure
E	Emissions coefficients	X	Exogenous data for calibration 1970
G	Growth rate type parameters	%	Ratio applicable to context
K	Capital coefficients	@	I-A input-output coefficient
L	Labour coefficients		
M	Miscellaneous parameters		

Source: Future of the World Economy (pp. 83-84) by Leontief et al., 1977, New York: Oxford University Press.

VITA

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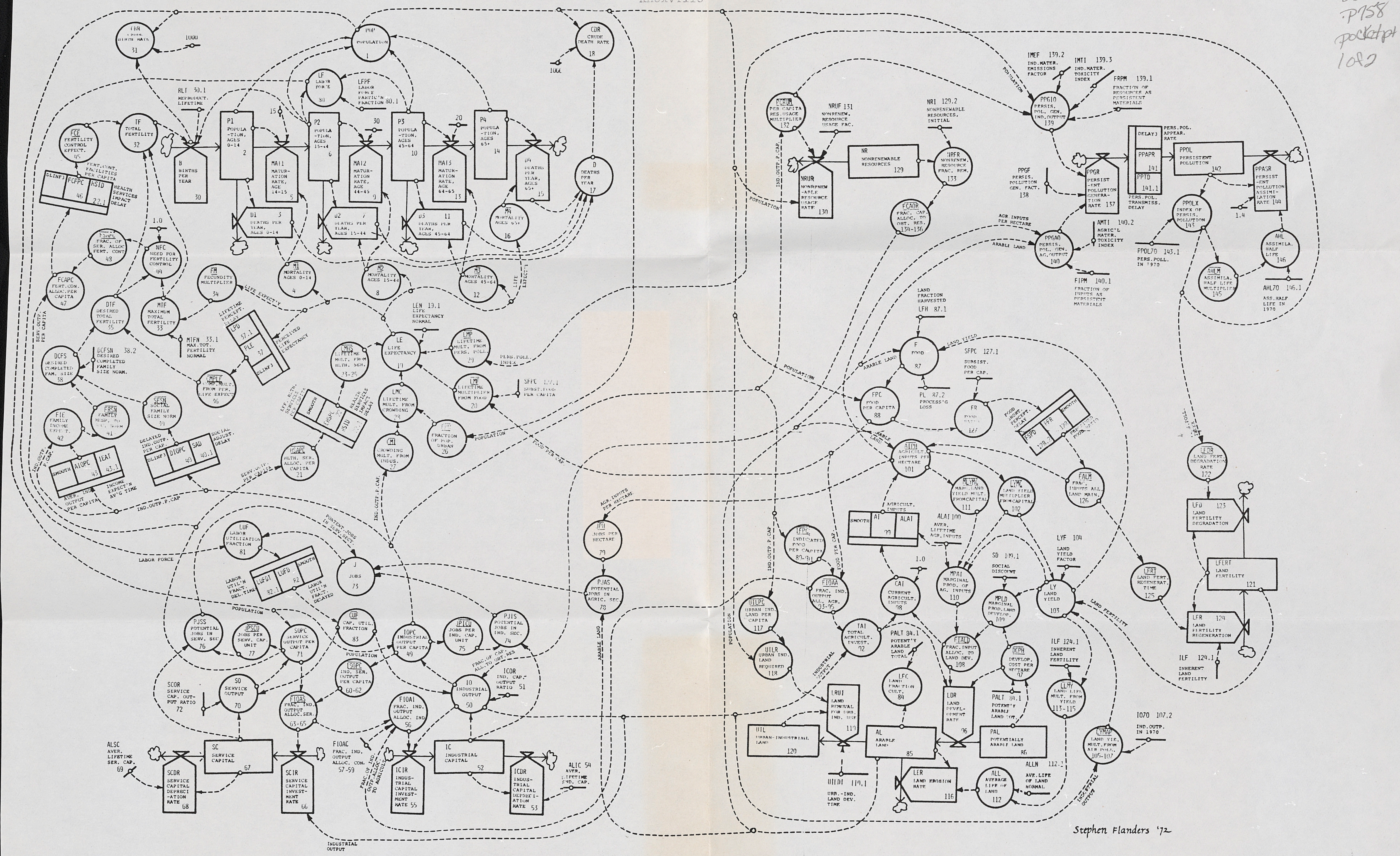
Ms. Pritchard entered the Graduate School of Planning of The University of Tennessee, Knoxville, in September 1983. She accepted a Graduate Assistantship for two years. During the summer of 1984 she was employed by the Tennessee Technology Foundation and in the summer of 1985 by the Tennessee Valley Authority. While at the University she was elected a member of Phi Kappa Phi. She received the degree of Master of Science in Planning in December 1985.


CBR CRUDE BIRTH RATE 31
POP POPULATION 1
CDR CRUDE DEATH RATE 18
1000
RLT 30.1 REPRODUCT. LIFETIME
LF LABOR FORCE 80
LFPF LABOR FORCE PARTIC'N FRACTION 80.1
FCE FERTILITY CONTROL EFFECT. 45
TF TOTAL FERTILITY 32
B BIRTHS PER YEAR 30
P1 POPULA-TION, AGES 0-14 2
MAT1 MATUR-ATION RATE, AGE 14-15 5
P2 POPULA-TION, AGES 15-44 6
MAT2 MATUR-ATION RATE, AGE 44-45 9
P3 POPULA-TION, AGES 45-64 10
MAT3 MATUR-ATION RATE, AGE 64-65 13
P4 POPULA-TION, AGES 65+ 14
D4 DEATHS PER YEAR, AGES 65+ 15
D DEATHS PER YEAR 17
FERT.CONT. FACILITIES PER CAPITA
HEALTH SERVICES IMPACT DELAY
DLINF3 FCFPC 46 HSID 22.1
D1 DEATHS PER YEAR, AGES 0-14 3
D2 DEATHS PER YEAR, AGES 15-44 7
D3 DEATHS PER YEAR, AGES 45-64 11
M4 MORTALITY AGES 65+ 16
FSAFC FRAC. OF SER. ALLOC FERT. CONT. 48
NFC NEED FOR FERTILITY CONTROL 44
M1 MORTALITY AGES 0-14 4
M2 MORTALITY AGES 15-44 8
M3 MORTALITY AGES 45-64 12
FCAPC FERT.CON. ALLOC.PER CAPITA 47
FM FECUNDITY MULTIPLIER 34
LIFE EXPECTANCY
DTF DESIRED TOTAL FERTILITY 35
MTF MAXIMUM TOTAL FERTILITY 33
LIFETIME PERCEPT. DELAY
LPD 37.1
PLE 37
DLINF3
PERCEIVED LIFE EXPECTANCY
LEN 19.1 LIFE EXPECTANCY NORMAL
MTFN 33.1 MAX.TOT. FERTILITY NORMAL
DCFS DESIRED COMPLETED FAM. SIZE 38
DCFSN 38.2 DESIRED COMPLETED FAMILY SIZE NORM.
CMPLE COMP. MULT. FROM PER. LIFE EXPECT. 36
LMHS LIFETIME MULT. FROM HLTH. SER. 23-25
LE LIFE EXPECTANCY 19
LMP LIFETIME MULT. FROM PERS. POLL. 29
PERS.POLL. INDEX
FIE FAMILY INCOME EXPECT. 42
FRSN FAMILY RESP. TO SOC. NORM 41
SFSN SOCIAL FAMILY SIZE NORM 39
HLTH. SERVICES PER CAPITA
SMOOTH
EHSPC
HSID
HEALTH SERVICES IMPACT DELAY
LMC LIFETIME MULT. FROM CROWDING 28
LMF LIFETIME MULTIPLIER FROM FOOD 20
SFPC 127.1 SUBSIST. FOOD PER CAPITA
DELAYED IND.OUTP. PER CAP.
SOCIAL ADJUST. DELAY
DLINF3 DIOPC 40 SAD 40.1
SMOOTH AIOPC 43 IEAT 43.1
AVER. IND. OUTPUT PER CAPITA
INCOME EXPECT'N AV'G TIME
HSAPC HLTH. SER. ALLOC. PER CAPITA 21
SERV.OUTP. PER CAPITA
IND.OUTP. P.CAP.
CMI CROWDING MULT. FROM INDUS. 27
FPU FRACTION OF POP. URBAN 26
POPULATION
FOOD PER CAP
IND.OUTP. P.CAP.
LABOR FORCE
LUF LABOR UTILIZATION FRACTION 81
POTENT. JOBS IN SERV. SECT.
LABOR UTIL'N FRAC. DEL. TIME
LUFDT 82.1 LUFD 82 SMOOTH
LABOR UTIL'N FRACT. DELAYED
J JOBS 73
JPH JOBS PER HECTARE 79
AGR. INPUTS PER HECTARE
PJAS POTENTIAL JOBS IN AGRIC. SEC. 78
PJSS POTENTIAL JOBS IN SERV. SEC. 76
JPSCU JOBS PER SERV. CAP. UNIT 77
SOPC SERVICE OUTPUT PER CAPITA 71
CUF CAP. UTIL. FRACTION 83
IOPC INDUSTRIAL OUTPUT PER CAPITA 49
JPICU JOBS PER IND. CAP. UNIT 75
PJIS POTENTIAL JOBS IN IND. SEC. 74
ISOPC IND. SER. OUTPUT PER CAPITA 60-62
FRAC.OF CAP. ALL.TO OBT.RES
ICOR IND. CAP.-OUTPUT RATIO 51
SCOR SERVICE CAP. OUT-PUT RATIO 72
SO SERVICE OUTPUT 70
FIOAS FRAC. IND. OUTPUT ALLOC.SER. 63-65
FIOAI FRAC. IND. OUTPUT ALLOC. IND 56
IO INDUSTRIAL OUTPUT 50
ARABLE LAND
ALSC AVER. LIFETIME SER. CAP. 69
SC SERVICE CAPITAL 67
FIOAC FRAC. IND. OUTPUT ALLOC. CON. 57-59
IC INDUSTRIAL CAPITAL 52
ALIC 54 AVER. LIFETIME IND. CAP.
SCDR SERVICE CAPITAL DEPRECI-ATION RATE 68
SCIR SERVICE CAPITAL INVEST-MENT RATE 66
FRAC.OF IND. OUTP.ALLOC. TO AGRICULT.
ICIR INDUS-TRIAL CAPITAL INVEST-MENT RATE 55
ICDR INDUS-TRIAL CAPITAL DEPRECI-ATION RATE 53
INDUSTRIAL OUTPUT
PCRUM PER CAPITA RES.USAGE MULTIPLIER 132
NRUF 131 NONRENEW. RESOURCE USAGE FAC.
NRI 129.2 NONRENEWABLE RESOURCES, INITIAL
IND.OUTP.P.CAP.
NRUR NONRENEW -ABLE RESOURCE USAGE RATE 130
NR NONRENEWABLE RESOURCES 129
NRFR NONRENEW. RESOURCE FRAC. REM. 133
FCAOR FRAC. CAP. ALLOC. TO OBT. RES. 134-136
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IMEF 139.2 IND.MATER. EMISSIONS FACTOR
IMTI 139.3 IND.MATER. TOXICITY INDEX
FRPM 139.1 FRACTION OF RESOURCES AS PERSISTENT MATERIALS
PPGIO PERSIS. POL. GEN. IND.OUTPUT 139
PPGF PERSIS. POLLUTION GEN. FACT. 138
PPGR PERSIST -ENT POLLUTION GENERA-TION RATE 137
DELAY3 PPAPR 141 PPTD 141.1
PERS.POL. APPEAR. RATE
PERS.POLL. TRANSMISS. DELAY
PPOL PERSISTENT POLLUTION 142
PPASR PERSIST -ENT POLLUTION ASSIMI-LATION RATE 144
AGR INPUTS PER HECTARE
ARABLE LAND
PPGAO PERSIS. POL. GEN. AG.OUTPUT 140
AMTI 140.2 AGRIC'L MATER. TOXICITY INDEX
PPOLX INDEX OF PERSIS. POLLUTION 143
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AHL ASSIMIL. HALF LIFE 146
PPOL70 143.1 PERS.POLL. IN 1970
AHLM ASSIMIL. HALF LIFE MULTIPLIER 145
AHL70 146.1 ASS.HALF LIFE IN 1970
FIPM 140.1 FRACTION OF INPUTS AS PERSISTENT MATERIALS
LAND FRACTION HARVESTED
LFH 87.1
LAND YIELD
ARABLE LAND
F FOOD 87
POPULATION
SFPC 127.1 SUBSIST. FOOD PER CAP.
FPC FOOD PER CAPITA 88
PL 87.2 PROCESS'G LOSS
FR FOOD RATIO 127
FOOD SHORT. PERCEPT. DELAY
FSPD 128 PFR 128 SMOOTH
PERCEIVED FOOD RATIO
ARABLE LAND
AIPH AGRICULT. INPUTS PER HECTARE 101
LDR LAND FERT. DEGRADATION RATE 122
MLYMC MARGINAL LAND YIELD MULT. FROMCAPITAL 111
LYMC LAND YIELD MULTIPLIER FROMCAPITAL 102
FALM FRAC. INPUTS ALL. LAND MAIN. 126
LFD 123 LAND FERTILITY DEGRADATION
AGRICULT. INPUTS
SMOOTH AI 99 ALAI
ALAI 100 AVER. LIFETIME AGR.INPUTS
LYF 104 LAND YIELD FACTOR
IND.OUTP. P.CAP.
IFPC INDICATED FOOD PER CAPITA 89-91
FOOD PER CAP.
1.0
CAI CURRENT AGRICULT. INPUTS 98
MPAI MARGINAL PROD. OF AG. INPUTS 110
SD 109.1 SOCIAL DISCOUNT
LY LAND YIELD 103
LFRT LAND FERT. REGENERAT. TIME 125
LFERT LAND FERTILITY 121
FIOAA FRAC. IND. OUTPUT ALL. AGR. 93-95
MPLD MARGINAL PROD. LAND DEVELOP. 109
LAND FERTILITY
UILPC URBAN IND. LAND PER CAPITA 117
TAI TOTAL AGRICULT. INVEST. 92
PALT 84.1 POTENT'Y ARABLE LAND TOTAL
FIALD FRAC. INPUT ALLOC. TO LAND DEV. 108
DCPH DEVELOP. COST PER HECTARE 97
LFR 124 LAND FERTILITY REGENERATION
ILF 124.1 INHERENT LAND FERTILITY
UILR URBAN IND. LAND REQUIRED 118
INDUSTRIAL OUTPUT
LFC LAND FRACTION CULT. 84
LLMY LAND LIFE MULT. FROM YIELD 113-115
LRUI LAND REMOVAL FOR URB. IND. USE 119
LDR LAND DEVEL-OPMENT RATE 96
PALT 84.1 POTENT'Y ARABLE LAND TOT.
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PAL POTENTIALLY ARABLE LAND 86
LYMAP LAND YIE. MULT. FROM AIR POLL. 105-107
ALLN 112.1 AVE.LIFE OF LAND NORMAL
UILDT 119.1 URB.-IND. LAND DEV. TIME
LER LAND EROSION RATE 116
ALL AVERAGE LIFE OF LAND 112
Stephen Flanders '72

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GNP    1    BAL    6    LABOR11    NFISH31    RSS   39    RSM   60    IEQP 97    SEQP  2    HRSS  7    HINVY36    MAGR 44    MXT  58    EAGS 81    ERSM 97    ESLK 21    PAGS 27    PRSM 43    PCAP 67
  CONS  2    IMPRT 7    NUTRN12    MFISH32    MRSLK48    XT    62    IPLT 98    SPLT  3    ECUMR16    HFAS 37    MRSS 45    MSER 77    EAGR 85    EXT  99    ECAP 22    PAGR 31    PXT  45    DUMMY68
    DSAVE 3    EXPRT 8    EMA  14    EFISH33    AGR  57    XNT  81    INVCH99    SINVY 4    SCUMR25    HRFAS38    MRSR 54    MTR  78    ERSS 86    ESER 18    MCAP 23    PRSS 32    PSER 64    0
      INV   4    POP   9    EMTOT22    AGS  34    RSR  58    ABATE87    IIRR  0    SFAS  5    HEQP 34    INICF39    MAGM 55    MAID 79    ERSR 95    ETR  19    CONST24    PRSR 41    PTR  65    0
        GOV   5    URBAN10    XFISH30    GMSUB38    AGM  59    ABSLK92    ILAND 1    SLAND 6    HPLT 35    MAGS 40    MRSM 56    MSLK 80    EAGM 96    EAID 20    DUMA 25    PAGM 42    PAID 66    0
```

1 GNP	M + + +	- + P				P	+					-		+	+ -			
2 SAVE	% P						P											
3 INV	-						+ + P P											
4 GOV	% -																	
5 BAL		-		P P				M		+ P	P P P P P	P P P -	P P P P P	P P P P +	+ -			
6 IMPRT		-		P						P	+ P + + +	P + +						
7 EXPRT		-		P									P + P + +	+ P + +				
8 LABOR	L L	L L	- L	L	L L L L	L L L L	L L											
9 NUTRN	M	M	-															
11 EMA	E	E E	-	E	E E E E	E E E M												
19 EMNA			- -			E												
27 ABDET						M -												
32 AGS	C C	C U	M	M M M @ M	@ @ @ @	@ @ @ @	S S S S S			+			-					
36 RSS	C C	C U	@	@	@ @ @ @	@ @ @ @	S S S S S				- +		-					
45 AGR	C C	C U	@	@	@ @ @ @	@ @ @ @	S S S S S				+		-					
46 RSR	C C	C U	@	@	@ @ @ @	@ @ @ @	S S S S S				+		-					
47 AGM	C C	C U	@	@	@ @ @ @	@ @ @ @	S S S S S				+		-					
48 RSM	C C	C U	@	@	@ @ @ @	@ @ @ @	S S S S S				+			-				
50 XT	C C	C U	@	@	@ @ @ @	@ @ @ @	S S S S S					+		-				
69 XNT	C C	C U	@	@	@ @ @ @	@ @ @ @	S S S S					M M		M M				
75 IEQP							-	G	G									
76 IPLT							-	G	G									
77 INVCH							-	G		G								
78 ECUMR					G				G - +									
87 SEQP		K	K	K	K K K K	K K K K	K K	-										
88 SPLT	K	K K	K	K	K K K K	K K K K	K K	-										
89 SINVY				K	K K K K	K K		-										
90 SFAS		G						-		+ G					G G			
91 SLAND				K	K			-										
92 MAGS				A						-		T						
96 MAGR					A						-	T						
97 MRSS					A +						-	T						
6 MRSR					A						-	T						
7 MAGM				D						D	D -	T						
8 MRSM											D D -	T			M			
10 MXT						A						- T						
29 MSER	M											- T						
30 MTR	M	M M										-						
31 MAID	M											-						
32 EAGS													-		T	B		
36 EAGR													-		T	B		
37 ERSS													-		T	B		
46 ERSR													-		T	B		
47 EAGM				D									D D -		T	B		
48 ERSM													D D	-	T M		B	
50 EXT														-	T		B	
69 ESER														-	T		B	
70 ETR														-			B	
71 EAID														-			B	
72 ECAP	M														-			
73 MCAP															-			B
74 DUMMY															-			